DESIGN AND DEVELOPMENT OF A
KNOWLEDGE-BASED FRAMEWORK FOR TROUSER PROCUREMENT:
Bid Evaluation Software Tool (BEST)

Volume III: Additional Reports and Papers

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13. ABSTRACT *(Maximum 200 words)*

Research has been carried out to design and develop BEST (Bid Evaluation Software Tool) a knowledge-based decision support system for evaluating the capability of an apparel manufacturer to perform on a contract. BEST has been developed in cooperation with major apparel manufacturers and has been successfully field-tested in collaboration with Levi Strauss & Company. BEST is implemented in Level-5 Object and runs under the MS-Windows environment on IBM-compatible personal computers.

This research effort has realized the vision of creating a knowledge-based decision support system for the objective evaluation of apparel contractors who can deliver the *right* quality product at the *right* time and at the *right* price. In doing so, it has pioneered the concepts of "vendor pre-qualification" and "vendor certification" central to effective and successful supply chain management. Finally, the "terms of engagement" module in BEST represents the first known successful effort to quantitatively assess the "working conditions" in apparel plants -- a key requirement as apparel manufacturing turns global.

This volume (the third of three volumes) is a compilation of key reports and papers from the research.

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* * *

Executive Summary

The Final Technical Report for the project entitled "Design and Development of a Knowledge-based Framework for Trouser Procurement" is being submitted in three volumes. The scope of the individual volumes is as follows:

Volume I Executive Summary Technical Report
[SJ-TR-PROC-9603]

Volume II Research Methodology
[SJ-TR-PROC-9603A]

Volume III Additional Reports and Papers (**This Volume**)
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[BACKGROUND ON BEST]

5

A Knowledge-Based Decision Support System for Apparel Enterprise Evaluation

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5.1 Introduction

Until recently, determining the ability of a manufacturing enterprise to produce and deliver a commodity has largely been a highly subjective process rather than as an informed decision-making process. The traditional approach relies heavily on the expertise, knowledge and experience of the evaluator. However, with the advancements in Knowledge-Based Systems (KBS) and Decision Support System (DSS), it is feasible to abstract and represent the expert knowledge and develop a knowledge-based approach. A Knowledge-Based Decision Support System (KBDSS) can determine various factors which affect the manufacturing capabilities and how these factors can be aggregated to

arrive at a quantitative index for the enterprise. Such an approach will result in consistent and reliable evaluations. Moreover, such expert knowledge can widely be dispersed throughout an enterprise. In this article, we present the details of the design and implementation of a knowledge-based system, which can assist decision makers to evaluate apparel manufacturing enterprises.

5.1.1 Decision Support for Source Selection

The practice of subcontracting is prevalent in many industries. The buying organization typically receives bids from several companies and selects one of them to carry out these operations as a subcontract. This process is known as *Source Selection*. Selecting the lowest bidder may appear to be beneficial at the time of awarding the contract, but it may not necessarily turn out to be the overall best value decision. This is because the total cost involved in the specific lowest bid contract may be higher than the initial bid, as a result of poor quality, or failure to fulfill the buyer's order on time. In order to get the best overall value for the buyer, there is a trade-off between the price quoted in the bid and the ability of the bidder to fulfill the contract efficiently. The objective of this knowledge-based system is to provide reliable decision support to quantify and evaluate the contractor's technological competence and ability to meet or exceed the performance requirements.

Deriving objective performance indexes from available subjective data and using them for capability evaluation is not uncommon. The Federal Aviation Administration (FAA) has derived performance indicators based on on-time arrivals and departures, lost baggage, etc. to evaluate the capabilities of different carriers. But no such performance indicators exist for evaluating apparel enterprises. In this article, we outline the methodology we incorporated to arrive at reliable indicators for evaluating apparel manufacturers and the implementation of this methodology in a knowledge-based decision support system. Once the validity/applicability of such an approach to apparel manufacturing enterprises is determined, it can be extended to other domains such as food, metal parts, and medicine.

5.1.2 Role of the Apparel Enterprise Evaluation System in Manufacturing Enterprise Architecture (MEA)

Computer-Integrated Manufacturing (CIM) involves integrating computers in various functions of an enterprise to produce the right product at the right time, right quality and right price (Jayaraman 1990). Therefore, an important prerequisite for the implementation of CIM is the in-depth knowledge about every function in the enterprise. A complete and structured definition of the knowledge of all the fundamental functions of the manufacturing enterprise is known as the Manufacturing Enterprise Architecture (MEA) (Jayaraman 1989a). The source selection process is one such functional

component of MEA and should be automated to the extent possible in order to achieve complete integration in an enterprise. Therefore, a framework encompassing the source selection process knowledge is an integral part of MEA. Such a framework for evaluating the capabilities of apparel enterprises is known as the Apparel Enterprise Evaluation Framework (AEEF).

5.1.3 Project Initiative

The U.S. Department of Defense (DoD) is the largest buyer of apparel items in the western world, procuring approximately $1 billion worth of apparel through contracting (DPSC 1988). As part of the procurement process, DoD is required to evaluate the manufacturing facilities of bidders on contracts. The old practice of using sealed bid procedures and awarding contracts to the lowest bidder is giving way to *Best Value Procurement*. Bidder selection will be more effective if reliable quantitative methods for evaluating the contractor's potential could be developed. An approach based on acquiring the existing compiled knowledge of apparel manufacturing and source selection from contracting experts, and representing it in a structured knowledge framework, can aid the development of such methods and indicators. This informed knowledge-based framework can not only benefit DoD, but also benefit the whole apparel industry in general, since subcontracting is very prevalent in the apparel industry. If a standard set of complex rules could be developed to act upon the knowledge of the bidders' technical capabilities, it can be used as a framework for evaluating them. Moreover, this approach has the potential to be extended to any type of manufacturing enterprise, by carrying out appropriate modifications in the knowledge-based framework.

5.2 Project Objective

The objective of this project has been to develop a system to assist evaluators in improving the quality of the decision-making process in source selection in apparel procurement. This objective has been achieved through the following steps:

1. Designing and developing a knowledge-based framework (AEEF) to determine the major factors which affect the capabilities of an apparel enterprise and how each of these factors affects the overall possibility of getting a quality product at the right time from that enterprise;
2. Implementing this knowledge-based framework in a Decision Support System, which can be used by apparel buyers to evaluate the capabilities of their contractors' apparel manufacturing facilities;
3. Developing a front-end user interface to obtain the necessary information from the contractors.

Utility trouser manufacturing has been chosen as the domain for this research

because it represents a significant segment of items procured by DoD (approximately 300,000 pairs per year). Once the system is developed for utility trousers, the framework can be augmented to include other apparel items.

The major effort in building the knowledge framework involves the transformation of the knowledge of measurable quantities obtained from the bidders (e.g., technology level of sewing machines, average experience of machinery operators, number of QC inspectors, etc.) into entities of higher levels of abstraction such as production capability, quality capability and financial capability. In AEEF, the transformation of observable data into higher levels of knowledge is based on information from literature, the analysis of responses to a questionnaire to experts in the area of apparel manufacturing and contracting, and discussions with experts.

5.3 Current Procurement and Source Selection Procedures

As the first step in building this knowledge-based decision support system, the literature in the area of source selection has been reviewed. The U.S. Defense Logistics Agency (DLA), the Defense Personal Support Center (DPSC) and DoD handbooks provide detailed descriptions of procurement and the formal source selection process with special reference to clothing and textiles contracts (Edwards 1989, DPSC 1988, DPSC 1989). DPSC also has a list of acceptable suppliers for use by DLA contractors in subcontracting (ASL 1985). If DLA contractors procure raw materials from these acceptable suppliers, they are not required to perform raw material inspection and testing.

Lange and Heuermann performed an in-depth analysis of the army's contractor evaluation program (Lange & Heuermann 1973 January). They concluded that past performance was the criterion used universally. In the context of vendor evaluation based on informal sources of information, they inferred that those efforts were at best, marginally effective. While reviewing the private industry's practices, they found that although *vendor evaluation* efforts are performed sometimes, *vendor rating* efforts are extremely rare. They also state that a few major companies had tried to establish formal, elaborate vendor rating systems, but abandoned these efforts, because they were found to be generally unworkable, unmanageable and often ineffective. The vendor rating systems were discontinued because the efforts required for maintaining the system as an effective management tool were not justified by the results achieved. In spite of these failures in implementing rating systems in the industry, the authors maintained that a system for evaluating and rating vendors is almost always essential. They finally recommended the use of the current capability of individual contractors for evaluation to the extent possible, instead of relying on past performance evaluation alone.

Barnaby and Bohannon conducted an investigation to determine the effectiveness of the Pre-Award Survey (PAS) as an indicator of a contractor's ability to meet the delivery schedule (Barnaby and Bohannon 1975). They recommended that information instruments such as the Pre-Award Survey Predictive Index, should not be instituted on an

on-going basis, because such instruments would be used as evaluative indices. Also, if an individual were to be evaluated based on these Pre-Award Survey Predictive Index numbers, the pressure would increase on the Pre-Award Surveyor to favor an individual organization and introduce bias in the determination of the index.

Cormany and Donnellan developed some criteria for evaluation of contractor potential in the procurement of major weapon systems (Cormany & Donnellan 1975). Schuman and Vitelli designed and performed a statistical experiment to evaluate certain indicators of contractor performance developed by the Air Force Logistics Command (Schuman & Vitelli 1978). They concluded that deliveries appeared to be based on the capability of the contractor, and contractual requirements of delivery seemed to be irrelevant except that they were the best guesses available for contractor capability. Pingel proposed a system for evaluating service contractors (Pingel 1981). McLennen outlined the feasibility of a decision support system for determining the criteria for source selection (McLennen 1984).

From the literature it is clear that the move is towards best value procurement and away from the lowest cost bid criterion. However, there is no literature citing the use or development of domain-specific knowledge-based decision support for bidder evaluation in apparel manufacturing contracts, thus providing necessary justification for this project.

5.4 Apparel Manufacturing and Quality Control

Literature in the area of apparel manufacturing and quality control was also reviewed to assess the effect of manufacturing technology and quality control practices on the overall capability of the enterprise and to serve as a means of acquiring knowledge for AEEF.

5.4.1 Importance of Technology on Production and Quality

Hodgins emphasizes the importance of higher levels of automation by stating that a non-automated process generally resulted in lower production and longer training periods for the personnel to achieve the desired level of product quality (Hodgins 1990). Eberly describes the effect of technology on the apparel enterprise as follows (Eberly 1990):

> "New technology, in terms of both computer hardware and software as well as advanced spreading and cutting equipment, offers apparel manufacturers two significant opportunities to improve their companies' performances and response times."

The apparel manufacturing handbook by Solinger discusses basic production standards and information on all the operations involved in apparel manufacturing

(Solinger 1980). The stepwise details of the individual manufacturing operations and their required standards can be found in Hudson (Hudson 1988). These sources strongly emphasize the importance of advanced technology on both quality and production rates.

5.4.2 Utility Trouser Manufacturing and Quality Control

The major official sources for the manufacturing and quality control of utility trousers are the military and federal specifications. These specifications have been developed for garments procured by DoD and other U.S. Government departments. The military specification for utility trousers specifies the design, construction, stitches and seams, operations, tolerances and quality assurance provisions for the manufacture of utility trousers (MIL 1984). The military standard provisions for evaluating quality of trousers specifies standards for sampling, inspection and classification of defects (MIL 1987). These specifications also refer to other military and federal specifications for buttons (V-B 1984), fasteners (V-F 1987), thread (V-T 1982), label (DDD 1987), cloth (MIL 1984), and sampling procedures (MIL 1964). These specifications and standards can be utilized to evaluate the operations performed by the apparel manufacturing enterprise in producing utility trousers.

Based on the literature reviewed in the areas of source selection, apparel manufacturing and quality control and knowledge-based decision support systems, the following major conclusions can be drawn:

1. Only highly subjective vendor evaluation programs exist in DoD as well as the industry and there are no vendor rating programs. These evaluation programs are prone to the introduction of personal bias and consider past performance as the *only* major criteria.
2. There is no existing domain-specific knowledge-based apparel manufacturing enterprise evaluation system, with emphasis on new technology.
3. More recently, there has been a move away from the lowest cost bid approach towards a performance- or capability-based selection procedure.
4. Level of technology can be used as an important indicator of an enterprise's production and quality capabilities.

5.5 Knowledge Acquisition

The development of a *knowledge-based decision support system* for the evaluation of enterprise capabilities has been carried out in three stages, viz., acquiring the knowledge, developing the knowledge framework and representing the framework as a computer-based system. The compiled knowledge existing in experts' minds and used in the evaluation process needs to be obtained in a structured format. Since the quality of knowledge framework heavily depends on the translation of the experts' evaluation skills

into computer-representable knowledge, the knowledge acquisition process is critical to the development of the framework. As the first step in the knowledge acquisition process, the following three means were identified:

1. Development and mailing of questionnaires to experts in the areas of apparel manufacturing and contracting, followed by analysis of responses;
2. Knowledge from published literature in the fields of enterprise evaluation and apparel manufacturing technology and quality control;
3. Interaction with experts.

5.5.1 Questionnaire to Experts

The purpose of the questionnaire was to solicit experts' opinions on criteria that can serve as measures of a "good" or "ideal" manufacturing facility (Jayaraman 1989b). With this objective in mind, eight major groups of factors were identified as being important for evaluating an apparel enterprise (see Figure 5-1). In addition, five major criteria for evaluating an enterprise's performance were identified (see Figure 5-2)

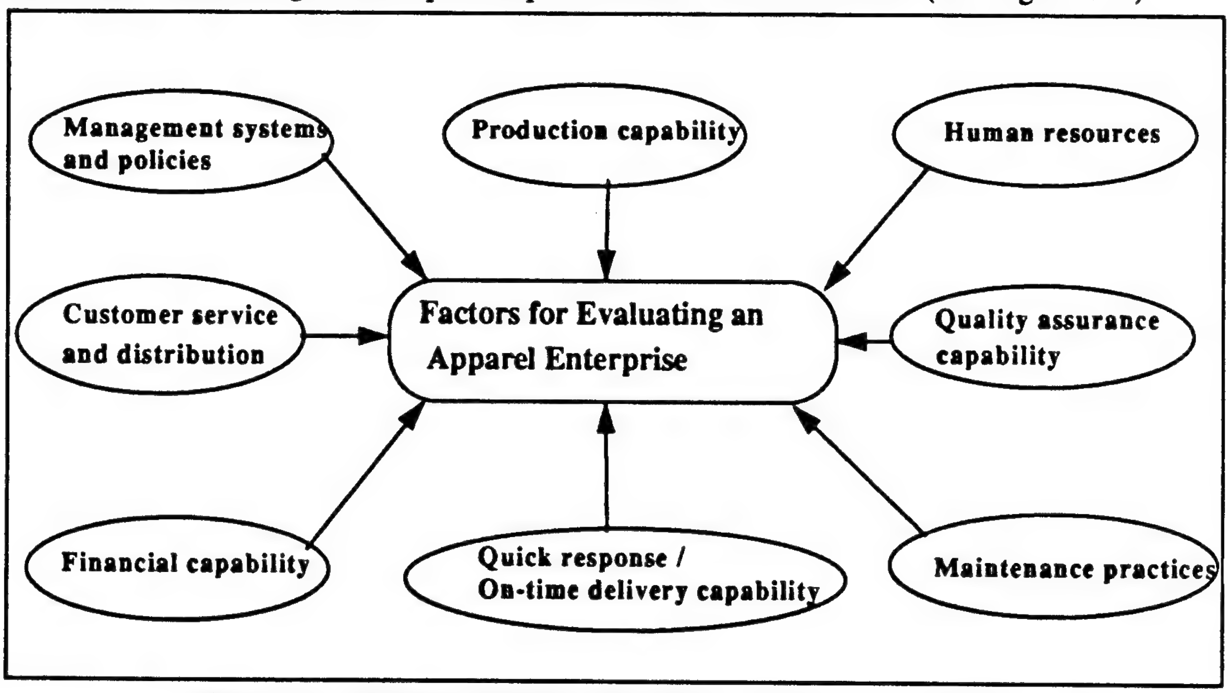

Figure 5-1. Groups of Factors for Evaluating an Apparel Enterprise

The questionnaire was divided into the following six parts, viz.,

1. Rank performance criteria
2. Rank capabilities
3. Rank processes
4. Process descriptions
5. Experience with contracting

6. Company and personnel information.

The first three parts of the questionnaire were designed to obtain the relative importance and weights of various criteria. The fourth part consisting of seven sections, dealt with specific questions about the following operational aspects of the enterprise[1]:

1. Raw Materials and Procurement Practices
2. Grading and Marker Making
3. Spreading and Cutting
4. Sewing
5. Packaging
6. Shipping and Distribution
7. Quality Assurance
8. Miscellaneous items such as Information Systems, Organizational Structure, etc.

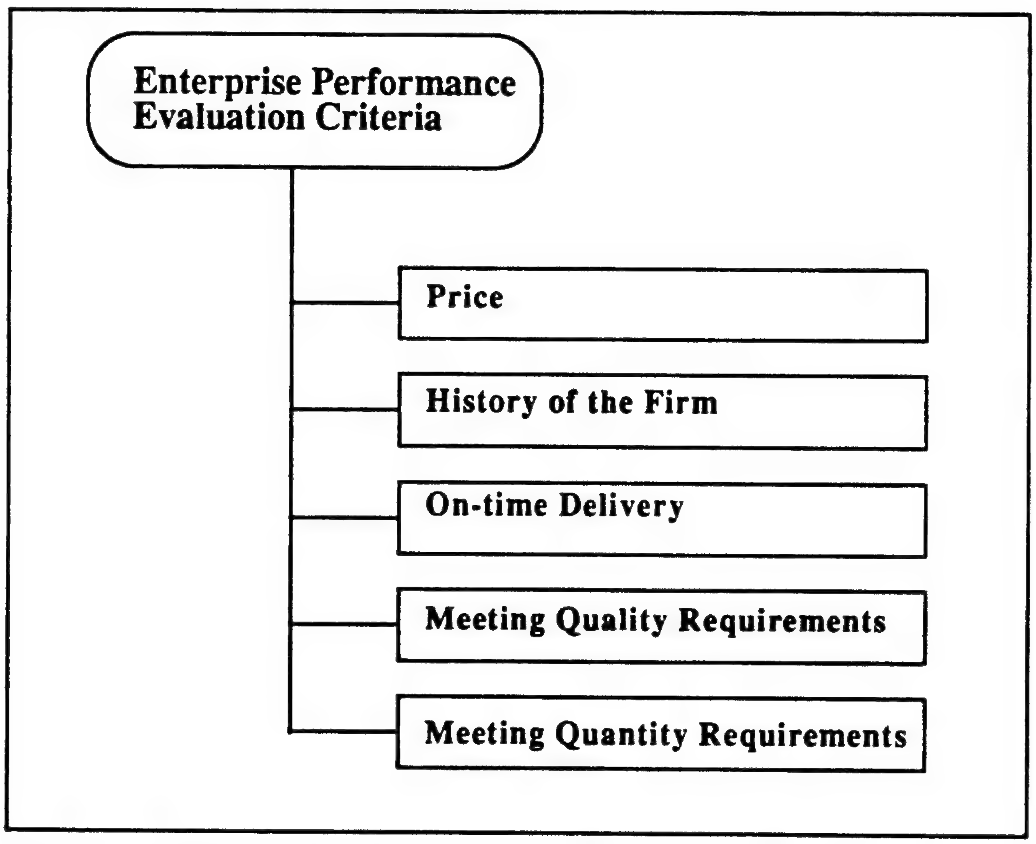

Figure 5-2. Criteria for Evaluating the Performance of an Enterprise

[1]Apparel manufacturing involves the following major process steps: Grading of patterns and marker making; Spreading and cutting of fabric; Sewing of cut parts; Inspection and packaging of finished garments; Shipping of packaged goods.

These questions were expected to facilitate obtaining the complete list of factors and their relative importances for all the operations carried out, operator capabilities, machinery capabilities and so on, in a utility trouser manufacturing organization. The questionnaire was mailed to over 500 apparel companies through American Apparel Manufacturers' Association (AAMA) and also sent to Defense Personnel Support Center (DPSC) and a few DLA field offices. The large number of questionnaires mailed out was to ensure that at least a few would respond; given the nature of the process, responses from more than a handful was not expected.

The questionnaire asked the respondents to rank the importance of various factors determining the capability of the bidder, and also to rank the importance of the questions themselves. This ranking of questions was also critical in determining the weights for the various factors influencing the decision making process.

5.5.2 Analysis of Questionnaire Responses

18 responses were received for the questionnaires sent. The distribution of the response sources were as follows: three military agencies, four federal contractors and eleven general apparel companies. A statistical analysis was carried out to obtain the relative importance of the questions and weights for the various factors[1]. Based on the analysis, different factors for evaluating a bidder have been allotted points reflecting their relative importance. The questionnaire responses have been augmented with the help of available literature in the area of apparel manufacturing and quality control, and fine-tuning the points by discussing the results of the analysis with a panel of experts in the apparel industry.

The analysis of the questionnaire indicated a very high degree of importance for quality control and quality assurance, and the sewing and cutting operations. Among the various evaluation criteria, meeting quality requirements and on-time delivery were ranked first and second, respectively (see Table 5-1). Quality assurance and production capabilities emerged as the factors having the maximum effect on performance (see Table 5-2) and quality control and sewing were ranked as the most important processes (see Table 5-3). The responses also clearly indicated that quality control activities should not be regulated by the production department. In other words, the quality control manager had to function independently of the production manager.

From the questionnaire responses, it is clear that quality control is the most important factor that is often evaluated for determining the capability of an apparel enterprise. Sewing, cutting and spreading are the three most important operations

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[1] The findings were not subjected through a rigorous statistical validation process. Since our objective of the knowledge acquisition process was to elicit and collect "subjective" data for implementation into a knowledge-based decision support system, and not just to draw conclusions based on statistical analysis, the number of responses were deemed adequate.

Table 5-1 Response Summary for Performance Criteria

(1 = Highest Rank, 5 = Lowest Rank)

Criteria	Mean Rank	Standard Deviation
Meet Quality Requirements	1.4	0.8
On-time Delivery	2.0	0.7
Price	2.7	1.0
Meet Quantity Requirements	3.1	1.3
History of the Firm	3.8	1.8

evaluated in the production of utility trousers. These operations are evaluated based on several factors including the level of automation, machinery features, floorspace, and operator capability.

5.5.3 Knowledge Acquisition from Literature

The effect of technology on the capability of the enterprise has been deduced primarily from literature. The importance of floor area on the quality and efficiency of spreading and cutting is emphasized heavily by Jones (Jones 1990). He also provides information for determining the space requirements for the spreading / cutting room. The level of spreading machinery technology depends on the features of the spreading machines viz., automatic tensioning, end catcher, etc. Solinger lists features that can be used for evaluating spreading machinery (Solinger 1980). Quality control standards and tolerances for sampling and inspection are obtained from literature (MIL 1964, MIL 1987, MIL 1984).

For cutting machinery, different kinds of high technology systems such as Numerically Controlled (NC) knife cutting, laser beam cutting and water jet cutting are available. But no documentation is available indicating conclusively the superiority of one system over the other. One major conclusion that can be drawn from literature is that a

Table 5-2 Response Summary for Effect on Performance

(5 = Maximum Effect, 1 = No Effect)

Criteria	Mean Effect	Standard Deviation
Quality Assurance Capability	4.8	0.5
Production Capability	4.6	0.6
Human Resources	3.9	1.0
Financial Capability	3.5	0.9
Quick Response Capability	3.4	1.2
Management System	3.3	1.1
Customer Service	3.1	1.2
Maintenance	2.9	0.8
Material Handling	2.3	1.2
Warehousing & Distribution	2.3	1.3

computer-controlled cutting system gives a higher production rate than manual cutting. In addition, a computer-controlled cutting system contributes to improved quality of the end product by producing more accurate cut parts. The sewing machines are also classified according to their contribution towards higher productivity and better quality, based on the level of technology.

The human resources in all the departments can be evaluated based on education, experience, wages, training, absenteeism, labor turnover, etc. In the U.S., salaries of apparel workers vary considerably based on the geographic location of the plant. Hence, a scheme is required for normalizing the widely varying wages. The apparel plants wages survey divides apparel plants into seven groups by geographic regions (Apparel 1989). It provides the average wages of all direct and indirect workers employed in an apparel

Table 5-3 Response Summary for Ranking of Processes

(1 = Highest Rank, 5 = Lowest Rank)

Process	Mean Rank	Standard Deviation
Quality Control	1.7	1.0
Sewing	1.7	0.8
Cutting	2.3	1.2
Raw Material Inspection	3.0	1.9
Packaging	3.8	1.8
Shipping	3.8	2.4

enterprise in every region. The wage structures within each geographic region tend to be reasonably similar. Therefore, this survey has been used to normalize the wages. A constant multiplier is derived for each geographical region and the details of wages obtained from the apparel enterprise can be standardized with this multiplier.

5.5.4 Interaction with Experts

In certain instances where it was not possible to obtain details either through the questionnaire responses or through the literature, discussions were held with experts in that specific area. For example, neither the questionnaire responses nor the literature yielded a reasonable range of annual labor turnover rate. The value was finally determined based on discussions with experts. Relative importances of most of the lower level criteria influencing the evaluation process were also determined with the help of experts.

5.5.5 Results of the Knowledge Acquisition Process

Thus, the three-step knowledge acquisition process yielded the following results,

which have then been utilized in building the knowledge framework:

1. Indicators of enterprise performance on contracts;
2. Abstraction of enterprise capabilities;
3. Importance of procedures and processes in apparel manufacturing;
4. Relative weights of various factors used in evaluation.

Quality, on-time delivery and price were identified as the three major indicators of contractor performance. Quality control and quality assurance practices emerged as the most important processes to be evaluated in determining the enterprise capability. Thus, the enterprise capability has been abstracted into quality, production and financial capabilities. These higher level abstract factors have been decomposed hierarchically to their sub-factors until the specific sub-factor becomes a parameter which can be observed or obtained from the enterprise being evaluated.

5.6 Choice Selection Methodologies and Selection of the Inference Mechanism for the Decision Support System

The design and development of this system falls in the category of choice selection procedures for ranking various alternatives based on different criteria with different weights. Multidimensional scaling and multi-attribute decision-making are two of the major techniques available for selection or rating of alternatives. Literature in these two areas has been reviewed and considered for implementation. Also, implementing this knowledge as an uncertainty management system for evaluation of manufacturing enterprises, based on the Dempster-Shafer theory of probability has been considered. This implementation would have resulted in a a probabilistic ranking of several alternatives. A fuzzy set formulation of this decision support system has also been considered.

The inference mechanism is crucial for the system to manipulate the knowledge base and arrive at the results. The information pertaining to the enterprise being evaluated is stored in the knowledge base and it must be manipulated by the inference mechanism to compute the rank or index of its capability to perform on a contract. Here the inference mechanism can be viewed as a method of ranking the specific enterprise in a pool of competitors and hence is also referred to as the *evaluation function*. Four techniques have been considered in developing the evaluation function for ranking the capability of the apparel enterprise. They are:

1. Multidimensional scaling
2. Multi-attribute decision making techniques
3. Probability techniques
4. Polynomial function

The following sections examine the feasibility of applying these techniques to AEEF.

5.6.1 Multidimensional Scaling

The multidimensional scaling technique uses a scaled rank for each attribute and the attribute's contribution towards the criteria being evaluated, to arrive at the multidimensional representation of the various candidates. The result is the positioning of each of the candidates in a space of *n* dimensions, where *n* is the number of factors/ attributes considered. However, an evaluation function is needed for computing the overall rating. The details of this technique can be found in several papers and textbooks (Green & Carmone 1972, Green & Rao 1972, Wind & Green 1973). Though no work has been reported on applying multidimensional scaling to vendor evaluation or similar problems, Wind et al. (Wind, Green & Robinson 1968) have demonstrated the feasibility of developing such an evaluation function. Ideally this would be the best evaluation strategy for a one-time evaluation process. But, for AEEF it is inappropriate for the following reasons:

1. The result is the positioning of the various candidate enterprises in scales of different attributes. The overall preference rating still needs to be calculated by some evaluation function.
2. The matrices to be manipulated are of dimensions **n** x **n** where **n** is the number of factors. In AEEF the number of factors will be in terms of hundreds.
3. There is no possibility of a hierarchical grouping of various factors.

Also, the reliability of this evaluation function is assured only if a large number of evaluators / respondents is used to assign the preference rating. Hence this technique is mostly suitable as a knowledge acquisition methodology for determining the weights of various attributes in an evaluation function. However, this technique has not been used in determining *Weights* for AEEF, since a simple statistical analysis could serve the purpose.

5.6.2 Multi-attribute Decision-Making Techniques

One of the multi-attribute decision-making methods for obtaining the relative ratings of more than two candidates, is the eigenvector method (Liu et al. 1990). In the eigenvector method, one or more evaluators assign the preference rating between pairs of the candidates on various attributes to form the matrix of preference rating entries. Each evaluator will have one preference rating matrix for each attribute. The eigenvectors of each of these matrices give the relative rating of each of the candidates. Hwang and Yoon (Hwang & Yoon 1981) provide complete details of the eigenvector method.

From the AEEF standpoint, the eigenvector method has the following disadvantages:

- The number of pairs needed for rating **n** candidates is ${}_{n}C_2$, which becomes very large even for a reasonable number of candidates.
- The more the number of evaluators, the better the statistical reliability of the result. Hence, this method requires a large number of evaluators for better quality of results.
- It does not take into account the relative importance (weights) of the factors contributing to the decision making parameter.

Though the number of pairs needed for evaluation can be reduced by a statistical sampling technique developed by Smith (BestChoice3 1990), the method becomes impractical for AEEF, owing to the other two reasons previously mentioned.

5.6.3 Probability Techniques

The bidder score can also be probabilistically determined from the bidder data. This scheme will provide the bidder score with confidence levels. For example, bidder A is assigned a score X with confidence level Y. The confidence level is a measure of the uncertainty introduced in the inference process due to unavailability of some required data. An average value can be substituted in the evaluation function for the missing data, but the confidence level will be reduced by a fraction. The reduction in confidence level will be proportional to the importance of the missing data. An important thing to note in this method is that another evaluation function is still needed for ranking the bidder.

There are some conceptual problems with the average value substitution and reduction of confidence level. As the system confronts a critical data to be unknown, the confidence level becomes 0 or near 0. A further reduction of confidence level is then impossible. Also, it is not possible to have a decision rule combining the ranking/score and the confidence level. This might lead to additional problems in decision-making rather than simplifying it. For example, a bidder who deserves a 10% score can obtain a score greater than 50% by not providing certain data. However, obtaining a higher score in this way is possible only at the cost of reduced confidence level.

5.6.4 Polynomial Function

A polynomial function can be used for evaluating any higher level entity based on the rank/score of the contributing lower level entities (see Figure 5-3).

where

$$Y = \sum_{i=1}^{n} X_i \tag{1}$$

Y is the score of the higher level entity;

n is the number of subclasses contributing to the higher level entity;

X_i is a polynomial function (of degree **m**) of the i^{th} entity's score (x_i),

which is of the form

$$X_i = \sum_{j=0}^{m} w_{ij} \cdot x_i^j \tag{2}$$

and

w_{ij} are the weights of the j^{th} power term in the polynomial for the i^{th} entity.

The polynomial ranking function is complete as well as complicated. However, it will be extremely difficult to get the values for all the coefficients w_{ij} for higher powers of **x** ($j \geq 2$) either from the questionnaire responses or from discussions with experts. Hence, for this system the polynomial has been simplified to a simple linear evaluation function of the form

$$Y = \sum_{i=1}^{n} w_i \cdot x_i \tag{3}$$

where

Y is the *Score* of the higher level entity;
n is the number of lower level entities contributing to the higher level entity;
x_i is the *Score* of the i^{th} entity and
w_i is the *Weight* of the i^{th} entity.

5.6.5 Working of the Inference Mechanism

The linear evaluation function given by equation (3) has been chosen for the inference mechanism. In the actual implementation, however, some offspring classes

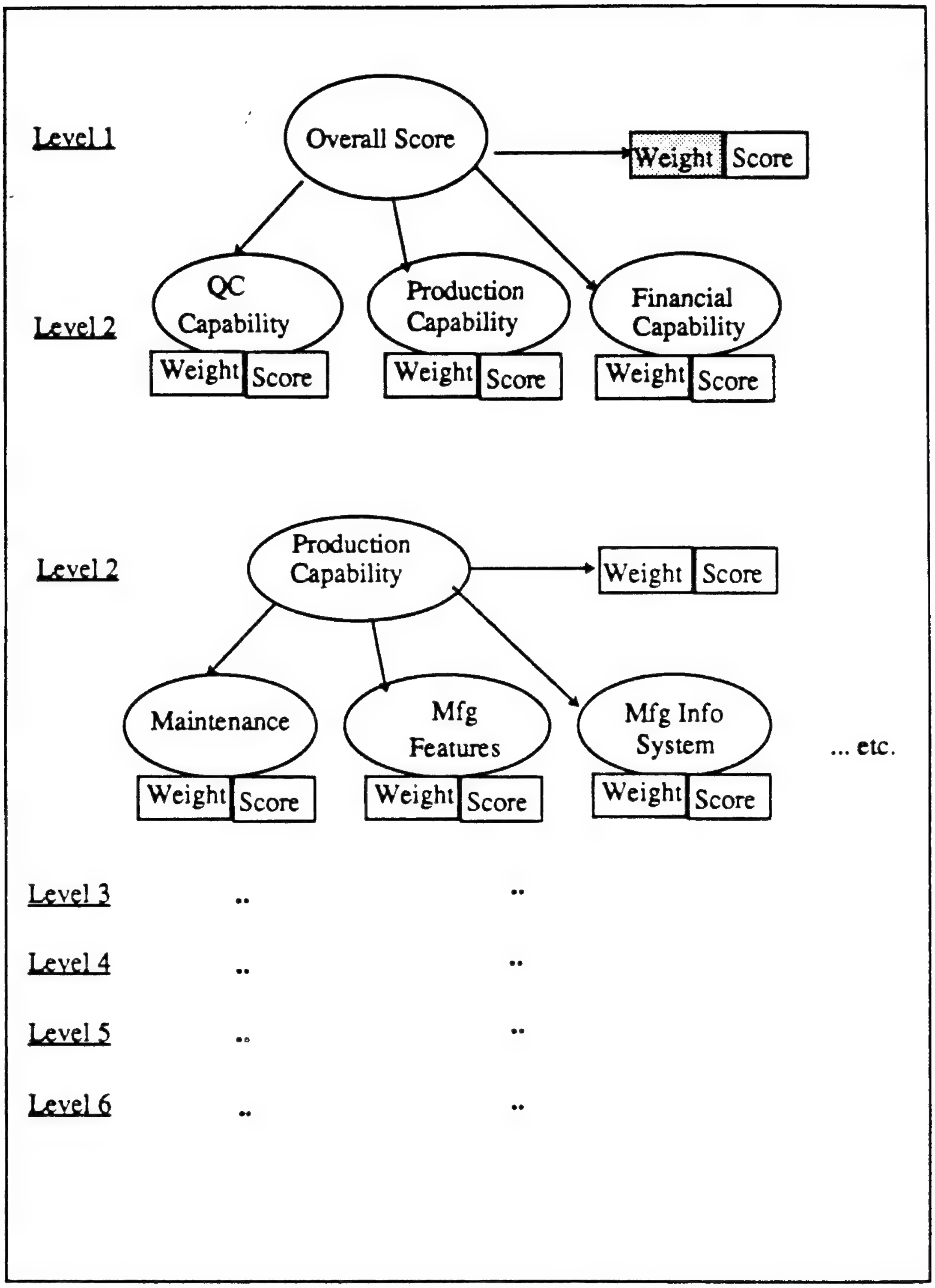

Figure 5-3. Inheritance of Properties by Lower Level Classes

contribute to more than one parent classes. This multiple inheritance, therefore, leads to a minor modification in the evaluation function, which is the addition of the parent index. The Score (Y_k) of the higher level class (**k**) to be evaluated is on the left-hand side, where

k is an index for the offspring to indicate that the class is the k^{th} parent. When there is no multiple inheritance, i.e., when all offspring has no more than one parent, the significance of the index k is ignored.

$$Y_k = \sum_{i=1}^{n} w_{ki} \cdot x_{ki} \qquad (4)$$

The variables in the function are the *Scores* of the offspring nodes (x_{ki}) and the coefficients are their respective *Weights* (w_{ki}) towards the object / class under consideration (k).

5.7 Design of the Knowledge Framework

The knowledge obtained from experts and literature for the development of AEEF is hierarchical in nature. Therefore, an object-oriented representation technique is well suited to represent the knowledge in a knowledge-based system. The factors used as criteria for evaluating the apparel enterprise are represented as *classes*. A hierarchical graph structure is followed for the successive decompositions of the classes into its subclasses (see Figure 5-3). With a few exceptions[1], all the properties of the parent class are inherited by the offspring; however, the value of the properties are not inherited down. An instance of a class (factor) is represented as an *object*. Every class and object belonging to a class has two basic properties, viz., *Weight* and *Score*. Figure 5-3 shows the two basic properties inherited from the Level One class *Overall_Score* by all its subclasses.

The property *Weight* is a decimal fraction value represented as the relative importance of that class with respect to *Weights* of all its sibling classes. Hence the sum of *Weights* of all the offspring of any class must always be 1. The property *Score* represents a ranking value calculated for that class from its subclasses. The *Score* varies between 0 and 4, with 0 being the lowest and 4 the highest score. During the start of an evaluation session, the *Score* of all classes is set to 0. The *Score* for the lowest level class is calculated based on appropriate heuristics which act on the other properties or features of that lowest level class. For example, if the sewing machine for producing pockets has an automatic positioning feature it will get the highest *Score*; on the other hand, if it only has cam control, it will get the next lower *Score*, and so on. This *Score* is utilized in determining the *Score* of the next higher level class and propagated upwards. This upward

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[1] These exceptions are only implementation dependent and not conceptual. When the children do not use all the inherited properties, the properties not used are manually pruned and only the needed properties are retained. This is to compensate for the nature of the implementation vehicle, Nexpert Object, which creates copies of the parent properties in the offsprings, instead of dynamically inheriting them.

propagation of the *Score* will continue until the highest level, i.e., the *Overall_Score* of the bidder is determined.

Though the major portion of the class hierarchy graph is a tree, in certain classes, multiple inheritance occurs from more than one parent. For example, manufacturing features is a factor that will contribute to both the production capability and the quality capability of a facility. Consequently, there will be more than one *Weight* and *Score* associated with that child class and these *Weights* and *Scores* will be indexed in order, for correct propagation to the right parent. For example, if the class *Mfg_Features* contributes towards both *Quality_Capability* and *Production_Capability*, it will have the properties *Weight* and *Score* for its propagation towards the class *Quality_Capability*, and *Weight1* and *Score1* for its propagation towards the class *Production_Capability*.

5.8 The Knowledge Network

As mentioned in Section 5.5, *Quality_Capability*, *Production_Capability* and *Financial_Capability* were identified as the three main factors for evaluating a bidder's facility. Thus, these three classes -- at Level Two -- contribute to determining the *Overall_Score* for the bidder at Level One, the highest level (shown in Figure 5-4).

The sets of factors based on which the questionnaire was framed are grouped under these three Level Two classes. For example, the factors human resources and maintenance, can be part of *Quality_Capability* as well as *Production_Capability*, as they contribute to both. Similarly on-time delivery is a result of good quality and production capabilities. So, these factors are subsumed by both the classes *Quality_Capability* and *Production_Capability*. Distribution and management policies received very low relative importance in the questionnaire responses; therefore, a separate class has not been created and the factors have been included as part of *Production_Capability*.

The three Level Two classes - *Quality_Capability*, *Production_Capability* and *Financial_Capability* - have been further decomposed hierarchically to identify the important subfactors that contribute to determining their values. The next level classification of the factors under *Quality_Capability*, *Production_Capability* and *Financial_Capability* is also shown in Figure 5-4.

Quality_Capability was considered to be the most important factor by 83% of the respondents to the questionnaire. *Production_Capability* was the next important factor. The relative weights of these three classes have been arrived at by proportionately distributing the relative importances of the factors grouped under the three classes. Table 5-4 shows the weights[1] of all classes (up to Level Three), eventually contributing to the *Overall_Score*. In this article, only the classes up to Level 3 are explained. A complete

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[1] These weights can be easily modified by the evaluators to suit the requirements on a specific procurement.

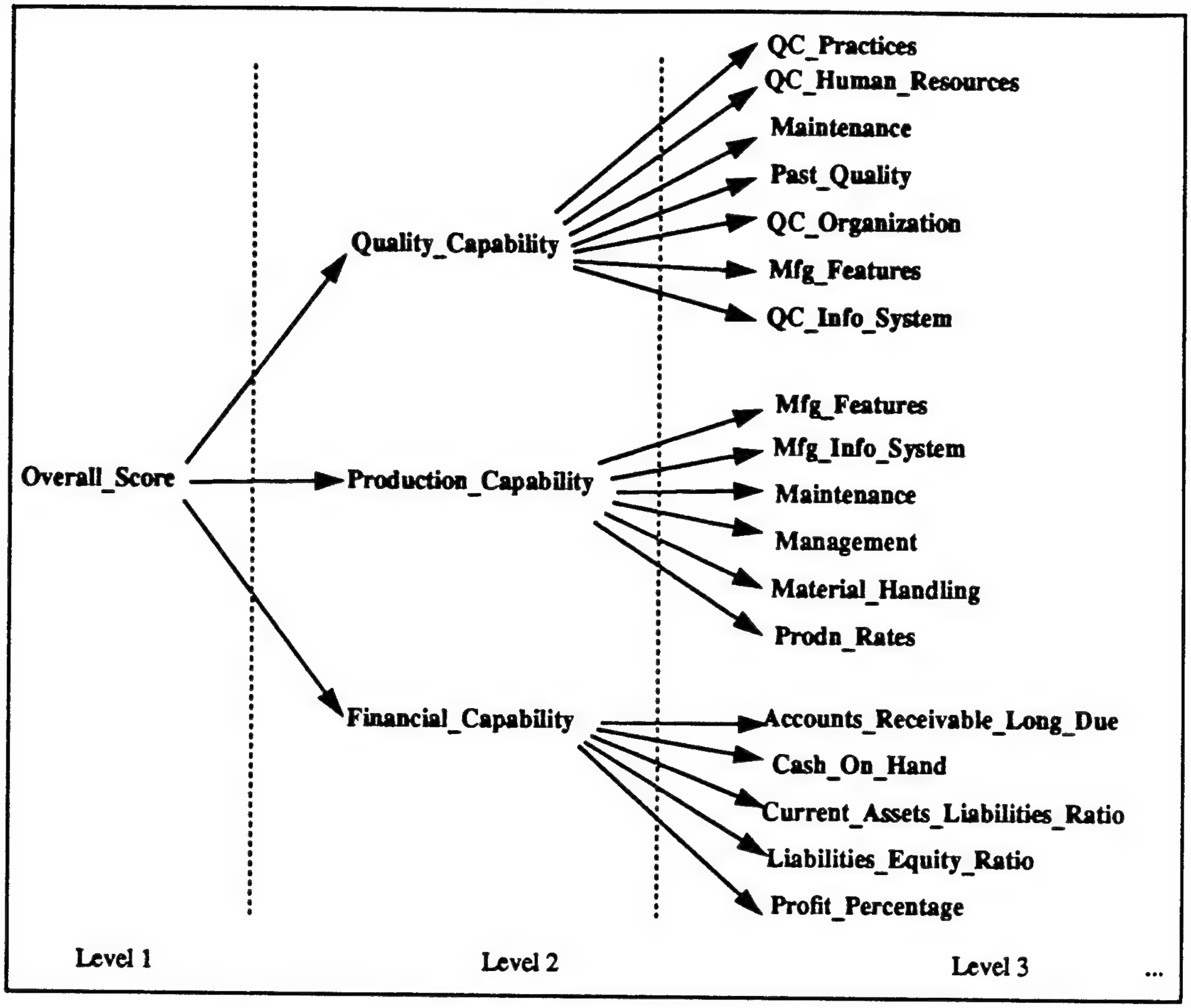

Figure 5-4. Decomposition of the Class *Overall_Score*

listing of the weights and a full decomposition of the knowledge network can be found in Narayanan 1991, and Narayanan et al. 1994.

5.8.1 Decomposition of the Level Two Class *Quality_Capability*

Figure 5-4 shows the various subfactors under *Quality_Capability*. Of these, *QC_Practices* has been identified as one of the important factors determining the *Quality_Capability* of an apparel enterprise. *QC_Practices* encompasses the quality control checks to be performed at every stage of the process, from raw material inspection to packaging. The evaluation process for determining the efficiency of the QC checks performed is complicated for at least three reasons:

1. The number of QC checks that can be instituted at every stage of the manu-

Table 5-4. Distribution of Weights

Overall_Score	
Quality_Capability.Weight	0.45
Production_Capability.Weight	0.35
Financial_Capability.Weight	0.20
Quality_Capability	
QC_Practices.Weight	0.27
QC_Human_Resources.Weight	0.18
QC_Info_System.Weight	0.10
QC_Organization.Weight	0.10
Mfg_Features.Weight	0.27
Maintenance.Weight	0.06
Past_Quality.Weight	0.02
Production_Capability	
Mfg_Features.Weight1	0.50
Prodn_rates.Weight	0.15
Mfg_info_system.Weight	0.10
Maintenance.Weight1	0.10
Material_Handling.Weight	0.06
Management.Weight	0.09
Financial_Capability	
Accounts_Receivable_Long_Due.Weight	0.10
Cash_On_Hand.Weight	0.40
Current_Assets_Liabilities_Ratio.Weight	0.30
Liabilities_Equity_Ratio.Weight	0.10
Profit_Percentage.Weight	0.10

facturing operation is fairly large.

2. Certain QC checks need not be performed in a specific enterprise either due to process differences or complete elimination of those corresponding defects.
3. Getting complete information from the bidder about all QC checks is very difficult from both the bidders' side and the evaluator's side.

Therefore, a scheme has been devised in which a select number of important QC checks is listed and the bidder can specify whether those QC checks are being performed in the facility. The list of selected QC checks has been compiled based on discussions with experts and results of a survey on apparel defects analysis (Srinivasan et al. 1992). A minimum number of QC checks should be performed to obtain a score equal to the minimum score. On the other hand, not all QC checks need to be performed to obtain the maximum score i.e., a major subset of the QC checks would be sufficient to obtain the maximum score. Therefore, any facility performing more than the built-in threshold upper limit of the number of QC checks to be performed will be assigned the maximum score. The need to perform raw material inspection checks is also waived if the bidder buys the raw material (except fabric, for which there is no Acceptable Suppliers List) from a supplier approved by DoD.

Manufacturing Features

The class *Mfg_Features* is one of the most important of the Level Three classes. It covers both the features of the production machinery, and the production personnel. Good machinery and an experienced and efficient work force largely determine the production and quality capabilities of the facility. Hence, *Mfg_Features* contributes to both *Production_Capability* and *Quality_Capability* as shown in Figure 5-5. Moreover, it has been considered to be an equally important factor as *QC_Practices* in contributing to the *Quality_Capability*.

The maintenance of quality in the QC department depends heavily on the QC personnel, and therefore *QC_Human_Resources* has been chosen as the third most important factor under *Quality_Capability*. Figure 5-5 shows the categories and attributes of personnel under the QC department that will be considered in the evaluation process.

Past_Quality Evaluation

In normal practice, past quality performance of the bidder is the primary factor in the evaluation procedure. However, in the informed knowledge-based approach, where the analysis of the data obtained from the bidder's facility gives a more reliable and accurate estimate of the capabilities, the past quality performance can be regarded as one of several factors. This is indicated by the low weight (2% of 45%) assigned to the class *Past_Quality*. Nevertheless, the past quality score needs to be calculated from the estimate of the evaluator. A simple procedure has been developed that takes into account the evaluator's estimate of the past quality performance of the bidder and the number of years the bidder has been in business.

During the evaluation of past quality performance, a score can be assigned by the evaluator for the number of years the bidder has been in business. If the bidder has been

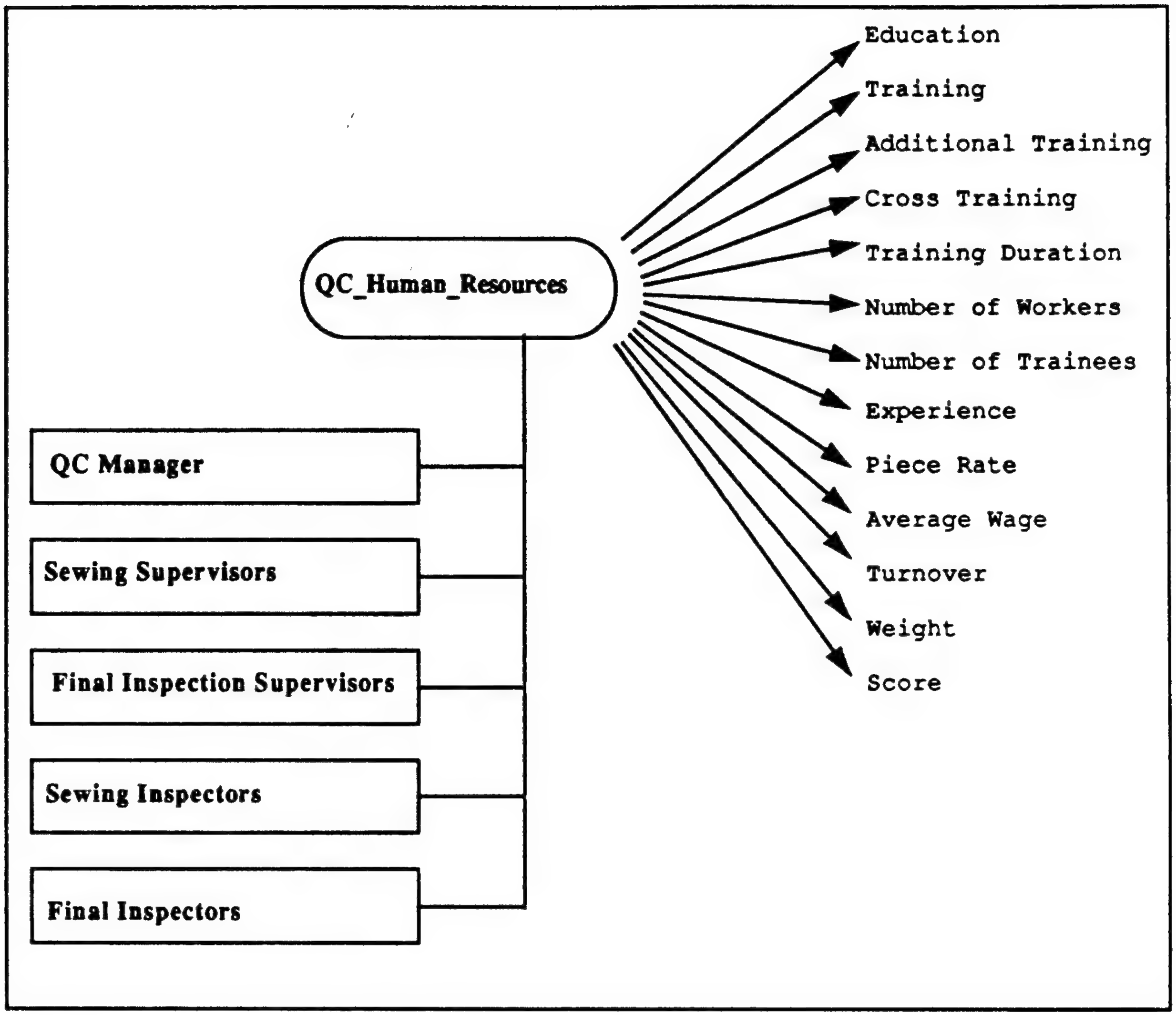

Figure 5-5. Categories and Attributes of Personnel in the QC Department

in business for a sufficiently long time (represented by the class *OK_Years_in_Business*), then this score itself would be appropriate as the *Past_Quality* score. On the other hand, if the bidder has been in business for only a short time, then the evaluator can assign a score considering only the known time frame i.e., the number of years the bidder has been in business (represented by the class *Years_in_Business*). A weighted average of the assigned score and an average score (2.0) is assigned for the unknown number of years (OK_Years_in_Business - Years_in_Business). Since a higher confidence level can be associated with the score assigned by the evaluator over the weighted average score, a weight of 80% is associated with the assigned score and 20% for the unknown years' score to arrive at the *Past_Quality Score*:

where S_i are the *Scores* and Y_i are the Years.

$$S_{PastQuality} = S_{Eval} \times 0.8 + \frac{S_{Eval} \times Y_{Known} + 2.0 \times Y_{(OK-Known)}}{Y_{OK}} \times 0.2 \qquad (5)$$

5.8.2 Decomposition of the Level Two Class *Production_Capability*

Mfg_Features is the single most important factor contributing to the *Production_Capability* of an apparel enterprise (Figure 5-4, Table 5-4). Next, the production rates (represented by the class *Prodn_Rates*) are important in determining the *Production_Capability*. An efficient production department also needs effective and well-designed information systems (*Mfg_Info_System*) and material handling systems (*MH_System*). Complementing these features are the *Maintenance* and *Management* as subclasses of *Production_Capability* in Figure 5-4. The effectiveness of management policies is determined based on whether there were strikes or lockouts in the past, any bonus was given to the employees in the past and the enterprise were unionized.

Manufacturing Features

Mfg_Features has been divided into *Mfg_Human_Resources* and *Machinery_Features*. The class *Mfg_Human_Resources* is very similar to the *QC_Human_Resources*. Apart from the standard attributes for the human resources, three additional attributes (the number of utility operators, the number of operators who can sew the seatseam, and number of operators who can sew any felled seam) have been defined for evaluating manufacturing human resources[1].

Grading and marker making machines, spreading machines, cutting machines and sewing machines are the four types of machinery considered in the class *Machinery_Features*. The number of machines in each category along with their capabilities determine the *Score* of these classes. Computerized grading and marker making, and numerically controlled cutting machines help in achieving higher productivity and quality and therefore they are given maximum scores in their respective categories.

Spreading machines are evaluated based on the features they possess (see Figure 5-6). For example, the existence of an automatic tensioning device will enhance the *Score* of the class *Spreading_Mach*, and if the spreading machine possesses all the features

[1] Seatseam and felled seam are the two critical operations in utility trouser manufacturing and have been selected as representative operations for evaluating the capability of manufacturing human resources.

listed, it will result in the maximum *Score* of 4.

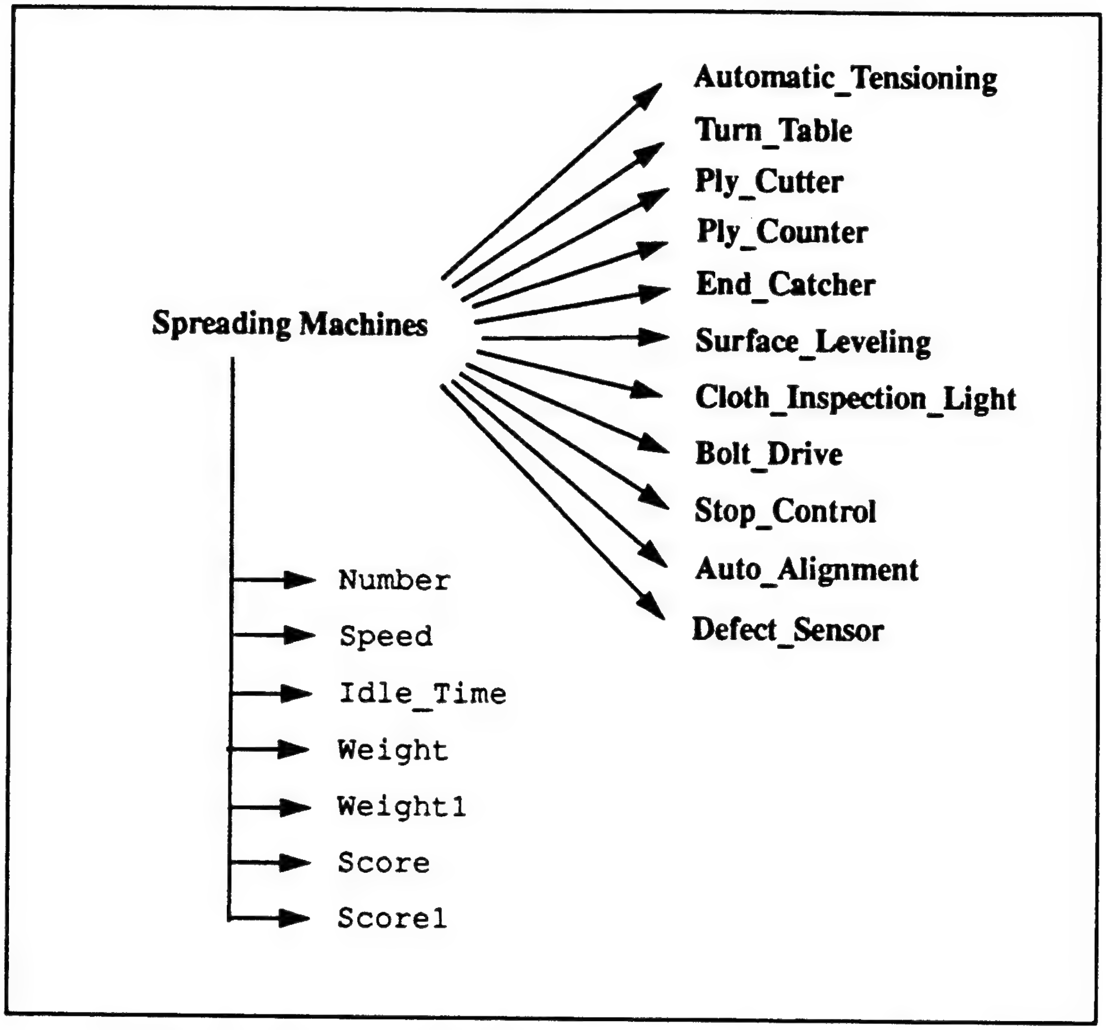

Figure 5-6. Spreading Machine Features and Their Attributes

Sewing Machine Classification

For most manufacturing operations, modern machinery incorporating higher levels of technology tends to reduce the proportion of defective units produced in a factory and causes fewer quality problems at higher production rates. But there is also a trade-off for the increase in technology level, as it is costly and the traditional measures of returns on investment (on a higher level of technology) start to diminish after a certain point. So it is crucial to identify for every operation, what technology level would be the best and what technology level would be the minimum requirement.

In an apparel manufacturing facility, sewing is the most important operation, and adds the maximum value to the fabric in its transformation into a garment. It would be sufficient if we could develop a good scale for the technology level required for a

sequence of operations to produce the garment, in this case, the utility trouser. But this process is quite difficult since the change in technology level often necessitates combining or splitting certain operations, and altering the sequence in which they are carried out. So it is necessary to have different sequences of operations, which represent the range from the best technology level to the worst.

Table 5-5. Technology Level Classification of Sewing Machinery

Feature#[1]	Feature	
1	Basic Machine	
2	Threadtrimmer Undertrimmer Felling Folder	OR OR
3	Cam Control Electronic Motor Control	OR
4	**Automatic Workaids** e.g. automatic belt loop cut & count automatic feed **button sew** **Programmable Electronic Motor**	 OR OR OR OR
5	Multifunction Programmable Fully Automatic	OR

[1] Better the features, higher the feature number.

To develop these sequences of unit operations, an important prerequisite is a scheme for the classification of technology levels. Sewing machines need to be classified into a specific order of technology levels based on their features and capabilities. A parameter ***Feature Number*** is defined to represent the technology level (the more advanced the technology, the higher the ***Feature Number***). The features and the classification of sewing machinery based on these features are given in Table 5-5. Also, a database of various sewing machinery available in the market, has been developed. It contains the manufacturer name, model name and number, a brief description of the machine, the technology level of the machine with supporting reason for the classification, the stitch type, cost, operating and maximum speeds, space occupied, training time required for operators and mechanics. This database was useful in estimating the space occupied by sewing workstations. It will also be useful in evaluating the sewing machinery available in the facility, and it should be expanded and updated frequently in order to reflect the frequent changes in technology.

Three sequences of operations representing the Worst-case, Mid-case and the Best-case technology levels have been developed for the production of utility trousers (Jayaraman 1989). The Best-case is the level of technology for a certain operation beyond which a higher technology level is either not essential or does not contribute to a higher quality or faster rate of production. Hence, a level of technology higher than the Best-case values are treated to be the same as the Best-case values for that specific operation. These best and worst technology level sequence values have been used in the evaluation process as the optimum and worst ***Feature Numbers***, respectively. Also, the best technology level sequence of operations has been used for determining the relative weights of some selected sewing operations (discussed in the following section).

Weight Determination for Sewing Operations

There are 23 unit operations in producing the utility trouser (MIL 1984) (see the operations under *Sewing Machines* in Figure 5-7). Since it may be difficult and even unnecessary to obtain information on machines used in all these operations, ten important operations have been identified. The importance of an operation is measured by the relative weight assigned for that operation. The criteria for determining the relative weights for the operations are that they must be:

- one of the most critical operations and
- the technology level of the machine required for that operation must be very high.

However, currently available technology levels of sewing machines for some of the critical operations are low. Hence, a combination of the criticality of an operation and the highest technology level of the machinery possible for that operation has been used as the relative weighting factor for each of the 10 operations. Proportionate weights are given to the technology level component as well as the criticality of operation component, which

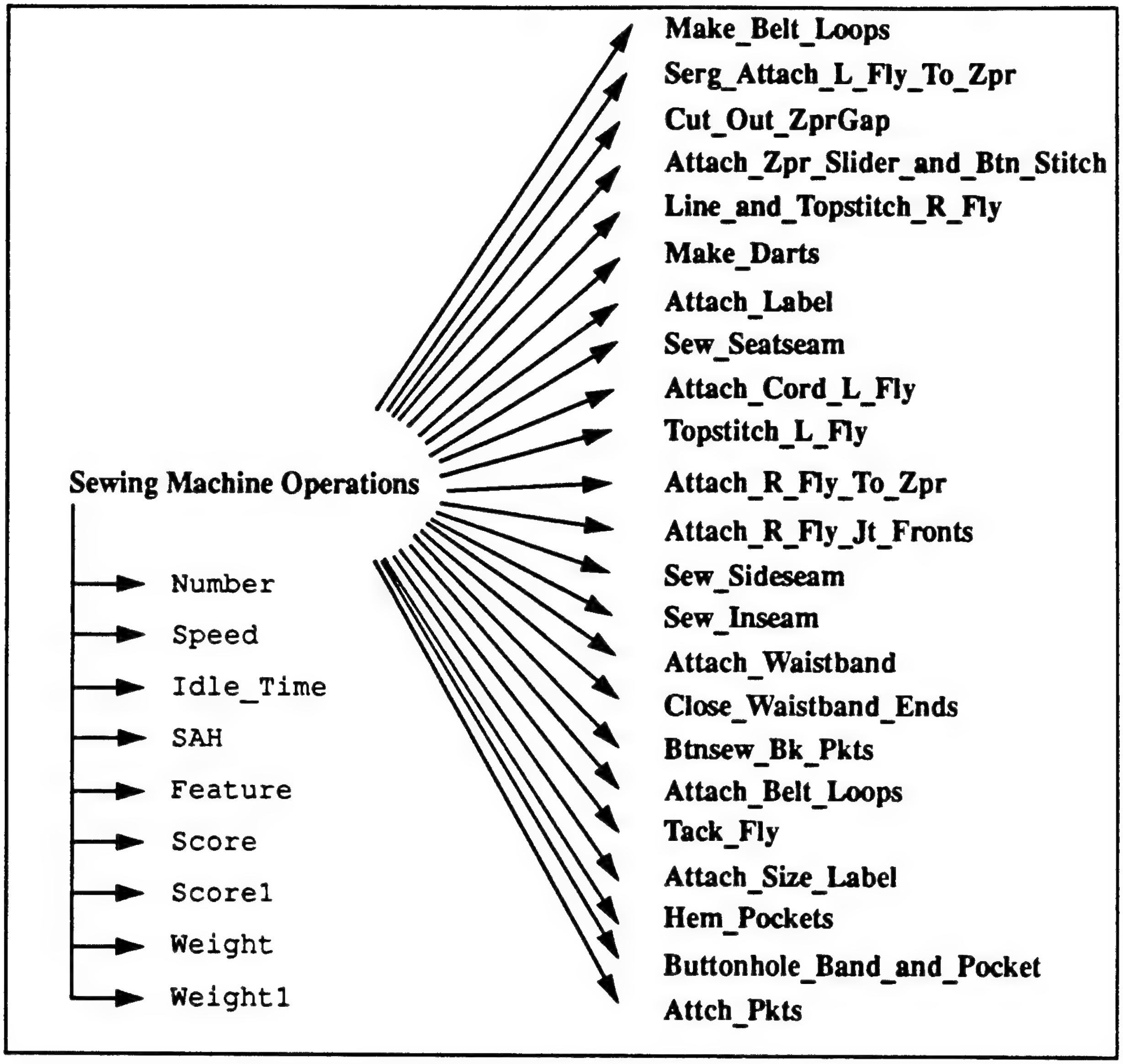

Figure 5-7. Sewing Machine Operations and Their Attributes

between themselves are weighted in the ratio 40:60. These component weights are added together to get the weight of the individual operations. The selected 10 operations, each with its respective criticality rank, best technology level possible (*Feature #*), weight for technology level and criticality, and the final *Weight* calculated, are shown in Table 5-6.

Maintenance

The effectiveness of maintenance is evaluated by the procedures and human resources utilized in maintenance. Also, the availability, and reliability of the machines can be a good indicator of the condition of the machinery.

Table 5-6. Determination of Weights for Sewing Operations

Operation	Best Possible Technology Level Feature #	Technology Level Weight	Criticality Rank	Criticality Weight	Weight
Attach Belt Loops	4	.04	4	.04	.08
Attach Label	5	.05	5	.02	.07
Attach Pockets	4	.04	4	.04	.08
Attach Waistband	4	.04	3	.06	.10
Make Belt Loops	4	.04	4	.04	.08
Make Darts	5	.05	3	.06	.11
Sew Inseam	3	.03	2	.09	.12
Sew Seatseam	3	.03	1	.12	.15
Sew Sideseam	3	.03	2	.09	.12
Topstitch Back Darts	5	.05	4	.04	.09
Total		.40		.60	1.00

The *Reliability* of the machines can be evaluated by the two standard parameters,

- Mean Time Between Failures (*MTBF*) and
- Mean Time To Repair (*MTTR*).

These two parameters can be obtained individually for the spreading, cutting and sewing machines. Also, a higher number of *Spare_Sewing_Machines* can improve the efficiency of the sewing department and thereby contribute to increased *Reliability.*

Material Handling

Automated material handling systems such as Automated Guided Vehicles (AGV), Unit Production Systems (UPS), can reduce the material idle time and thereby improve the production capability of an apparel enterprise. Also, the ease of material handling is determined by the amount of space available per machine. A very high machine area to total area ratio indicates insufficient material handling space, whereas a very low ratio indicates lot of wasted space.

Production Rates

Sewing is the most labor intensive and most important of the various steps in apparel manufacturing. Moreover, it tends to be the principal factor affecting the output of the enterprise. Consequently, assessment of the sewing capacity will provide a good indication of the bidder's production rates and hence, the capacity. Therefore, only *Sewing_Capacity* is taken into account while evaluating *Prodn_Rates*. The decomposition of *Sewing_Capacity* is very similar to the decomposition of *Sewing_Mach*, where only the selected 10 sewing operations have been utilized in the evaluation. The sewing capacity of each of these operations is estimated based on the comparison of Standard Allowable Hours (*SAH*) for that operation, number of sewing machines allocated for that operation, working hours per day, and the number of trousers to be assembled per day.

Manufacturing Information Systems

The bidder's inventory control system, scheduling system, maintenance of production records and traceability of order status to the departments and to the individual sewing machines have been chosen as the four most important factors determining the effectiveness of the manufacturing information system The existence of separate control systems for fabric, trim (buttons, zippers, thread, etc.), finished goods and other supplies determines the effectiveness of the *inventory control system*. The purchase lead times for the various raw materials are indicators of the effectiveness of the inventory control system. The *Scheduling_System* is evaluated based on the schedule update frequency and computerization of the process. The existence of cut order delivery performance records, and their being on-line are also used as important criteria for evaluation of the manufacturing information systems.

5.8.3 Decomposition of the Level Two Class *Financial_Capability*

The class *Cash_On_Hand* is a crucial indicator of the financial status of the company (see Figure 5-4). Too little cash or too much cash indicate unhealthy situations. If a major portion of the accounts receivable is long overdue (more than 6 months), the chances of collecting them become remote and hence is viewed negatively. Also, values of current assets vs. liabilities ratio, liabilities vs. equity ratio and profit percentage should neither be too low nor too high. Thus, these five factors have been considered in evaluating the financial capability of the enterprise (see Figure 5-4 for details).

5.9 Software Implementation of Decision Support Tool

Automation is one of the important keys to productivity. The development of the knowledge framework for the evaluation of apparel enterprises (AEEF) leads to the next logical step of automating the evaluation process. However, total automation of the evaluation process may not be the best solution. There are numerous unknown factors which, in addition to the capabilities evaluated by the framework, may influence the decision-making process. Hence the framework should be used to automate the evaluation process only to the extent that it serves as a decision support tool for the human evaluator. Therefore, the knowledge-based framework has been implemented as a decision support system, with an appropriate implementation vehicle.

5.9.1 Selection of Software Implementation Vehicle

A hierarchical object-oriented representation technique has been adopted to represent the knowledge acquired in a computerized system (Narayanan et al. 1994). AEEF also consists of a large number of rules which act on the information about the apparel enterprise to determine its capability. Hence, a hybrid of object-oriented representation and rule-based inference strategy is required for an efficient implementation of AEEF as a knowledge-based system. The object-oriented expert system shell "Nexpert Object" has been selected for the implementation, since it supports both object-oriented representation of knowledge and rule-based reasoning strategies to act on the objects. Another requirement is that the resulting knowledge-based system be available on MS-DOS, as well as the UNIX operating system, so that it can be used by a large number of people. Consequently, the availability of Nexpert Object on both UNIX and DOS operating system environments has been a major factor in its selection as the implementation vehicle. Srinivasan performed a comparative study of Nexpert Object, other expert system shells and traditional programming languages (Srinivasan 1991). He discussed the advantages of Nexpert Object as a knowledge-based system development tool in terms of faster prototyping, easy linkage to other languages and databases, availability on various platforms, etc. He recommended Nexpert Object for an efficient implementation of object-oriented and rule-based hybrid knowledge-based systems. He also made an economic justification for the selection of Nexpert Object, when compared

with other expert system shells.

5.9.2 Implementation of the Knowledge Framework

The development version of Nexpert Object provides a graphical representation tool which contains a set of form-based editors (Nexpert 1988a,b). Different editors are available for creating and editing classes, objects, properties, and rules. When these form-based graphical editors are filled, the system automatically generates the code in ASCII format, which is portable across UNIX, MS-DOS and Macintosh platforms. The knowledge base and the inference engine for bid evaluation software tool (BEST) have been created with the help of Nexpert Object's form-based editors.

The conceptual framework of criteria for evaluation has been represented as a hierarchy of Nexpert Object *classes* (Narayanan et al. 1994). The Nexpert Object class can have *subclasses* as well as *properties*. The individual contractor details are represented as *objects*, which are created as instances of the classes defined. The attributes of the contractor details are represented as *properties* of the classes.

The knowledge base is mainly composed of a set of *If-Then* type of production rules. The rule has a *condition* part which is verified by the *If* clause, and a *hypothesis* part which is set to *True* if the condition is satisfied and *False* if the condition is not satisfied. The rules are identified by a unique rule number and are alphabetically ordered according to the hypotheses. The rules also have an *action* part on the right hand side, which triggers additional knowledge processing or data alterations, if and only if the hypothesis becomes *True*. A sample rule is given in Figure 5-8. If a rule has to be fired, data required by the condition part of the rule should be provided to the system. The process of supplying data required by a rule for its firing is known as *volunteering*.

There are two types of rules in AEEF. The lower level rules are the *knowledge* rules, which compute the *Score* of the lower level objects from the properties and values of the lower level enterprise details. For example, if the number of knots or splices in 1000 meters of the sewing thread is less than or equal to 1, then a *Score* of 4 is assigned to the class *Knots_Splices*. The first rule in Figure 5-8 (Rule R11) is also an example of a knowledge rule. The higher level rules are the *propagation* rules, which propagate the *Score* from lower level objects to a higher level object. These propagation rules are part of the inference mechanism, but they do not compute the scores from AEEF's knowledge network. They just derive the score of higher level objects from the *Score*s and *Weight*s of the lower level objects. The second rule (Rule R481) is an example of a propagation rule.

The calculation of the *Score* of a higher level object with the propagation type of rules requires that the *Score* of the lower level objects be already computed. These precedence constraints impose a sequence for the firing of the rules. This sequence is

```
(@RULE= R11
    (@LHS=
        (> (|Attch_Waistband|.Feature - Worst_Attch_Waistband) (0))
        (< (|Attch_Waistband|.Feature - Best_Attch_Waistband) (0))
    )
    (@HYPO= Atch_W_Band)
    (@RHS=
        (Do (4*(|Attch_Waistband|.Feature - Worst_Attch_Waistband)/
                (Best_Attch_Waistband - Worst_Attch_Waistband))
            (|Attch_Waistband|.Score))
    )
)



(@RULE=     R481
    (@LHS=
        (>=  (Lot_Size)        (0))
    )
    (@HYPO  =  Thread_Stds_Score_Dtmd)
    (@RHS  =
        (Do
            (|Thread_Elongation|.Weight  *|Thread_Elongation|.Score +
             |Knots_Splices|.Weight  *  |Knots_Splices|.Score)
        (|Thread_Stds|.Score))
    )
)
```

Figure 5-8. Sample Knowledge and Propagation Rules

established by modifying the properties of the *meta-slot* of the rule hypothesis (see Figure 5-11). The meta-slots have many properties such as the Inference Category Number, Initial Values, Inheritance Strategies, and Prompt Line, which can control the inference process. For instance, when the Inference Category Number is used to control the order of firing of the rules, the lower the value of the number, the later the rule will be fired. Thus, if rule A requires the result of rule B, rule B will have a greater Inference Category Number than rule A, and consequently, rule B will get fired first.

Figure 5-9. Inference Strategy Control Through Meta-Slot Editor

Another important use of meta-slots is for the initialization of the *Scores* without having additional rules. This is achieved by setting the *initvalue* of the meta-slot of the highest level class *Overall_Score*'s property, *Score*, to 0 and propagating the values to all the subclasses. The meta-slots are also used to control the inheritance strategies. For example, the inheritance of *Score* to all lower level classes should take place only for the initial value of zero. Subsequently, when knowledge processing takes place, the values should not propagate downwards. Otherwise, all the lower level scores would be lost. The meta-slot properties stop the inheritance of values once knowledge processing starts. The meta-slots also control user interaction with the system during knowledge processing. The system's prompts asking the user to input the values of objects, can be modified by altering the *Prompt Line* field. For example, the system can ask the user to "Enter the Master Data File Name:" instead of asking "What is the *Value* of *File_Name*?", by modifying the meta-slot *Prompt Line*.

5.9.3 User-Modifiable Decision Variables

The knowledge processing mechanism makes use of various decision variables derived from the knowledge framework. These decision variables are subjective in nature. Hence for different needs, these decision variables may need to be modified. Also, the present standards or specifications may become obsolete. For example, when new specifications that supersede the current military specifications for manufacturing and quality control of utility trousers are issued, some parameters, e.g., existing tolerances and sample sizes may change. The system should be able to handle these changes. These decision variables are not hard coded into the knowledge base, but they are called from the rules as *volunteer data*. In the present system, the values of these decision variables are stored in an ASCII text file. This file is known as the *parameter file* and it can be modified very easily with any line or screen text editor. Some example data from the current parameter file are shown in Figure 5-10.

```
Max_Fabric_LT                                     8         Weeks
Max_Trim_LT                                       4         Weeks
Max_Spare_Parts_LT                                6         Weeks

Min_Cutting_MTBF                                  100       Hours
Min_Sewing_MTBF                                   50        Hours
Min_Spreading_MTBF                                100       Hours
Max_Cutting_MTTR                                  60        Minutes
Max_Sewing_MTTR                                   40        Minutes
Max_Spreading_MTTR                                60        Minutes

OK_Cutting_MTBF                                   500       Hours
OK_Sewing_MTBF                                    250       Hours
OK_Spreading_MTBF                                 500       Hours
OK_Cutting_MTTR                                   20        Minutes
OK_Sewing_MTTR                                    15        Minutes
OK_Spreading_MTTR                                 20        Minutes



LT          -> Lead Time
MTBF        -> Mean Time Between Failures
MTTR        -> Mean Time To Repair
```

Figure 5-10. Example Data from Parameter File

The *Weights* are also decision variables, which may need to be modified according to specific evaluation needs. Therefore, the *Weights* are entered in a file known as the *weights file* (Narayanan 1991). The weights file contains information in an ASCII text file. The information obtained from the apparel enterprise being evaluated is also maintained in a set of ASCII text files that are collectively known as *contractor files*. These files are handled through a "C" program, which runs the evaluation system by calling Nexpert Object's subroutines. This program calls a subroutine from the action part of the right hand side of a rule for volunteering the enterprise data from the contractor files sequentially.

5.9.4 The Bid Evaluation Software Tool (BEST)

The implementation of the knowledge framework as a decision support system has resulted in the Bid Evaluation Software Tool (BEST). As shown in Figure 5-11, BEST consists of three main modules: the *Enterprise Information Entry Module*, the *Knowledge Processing Module* and the *Results and Explanation Module*. It accepts the information about the apparel enterprise being evaluated, processes the information with the help of the knowledge framework (BESTProcess) and provides a summary of the results on the screen. The knowledge processing can also be carried out in **transcript** mode, which provides a step-by-step account of how the *Score* for every object is computed. The results as well as the transcript can be stored in text files for comparing several enterprises. The input to the BEST system (the set of enterprise information files) is generated by a form-based user interface system.

In a decision support system, modularity is extremely important. Therefore, the user interface module is built as a separate, but cooperative module from the knowledge processing modules. This separation of the user interface module and the knowledge processing module would help immensely when BEST is ported to different user interface platforms. Only the Enterprise Information Module would need to be altered while the Knowledge Processing Module would remain the same, thereby facilitating an easy porting process.

5.10 User Interface for BEST

The user interface is one of the major factors that determine the success or failure of a software system like BEST. Therefore, a front-end user interface for obtaining data from the bidder's apparel manufacturing enterprise has been designed for BEST. This front-end will be used by individuals in various departments of the enterprise, who would fill the data in the specified format. Since these users will not necessarily be computer experts, the interface should be simple and user friendly. The interface features of the BEST system's front-end viz., the Enterprise Information Entry Module, are discussed in this section.

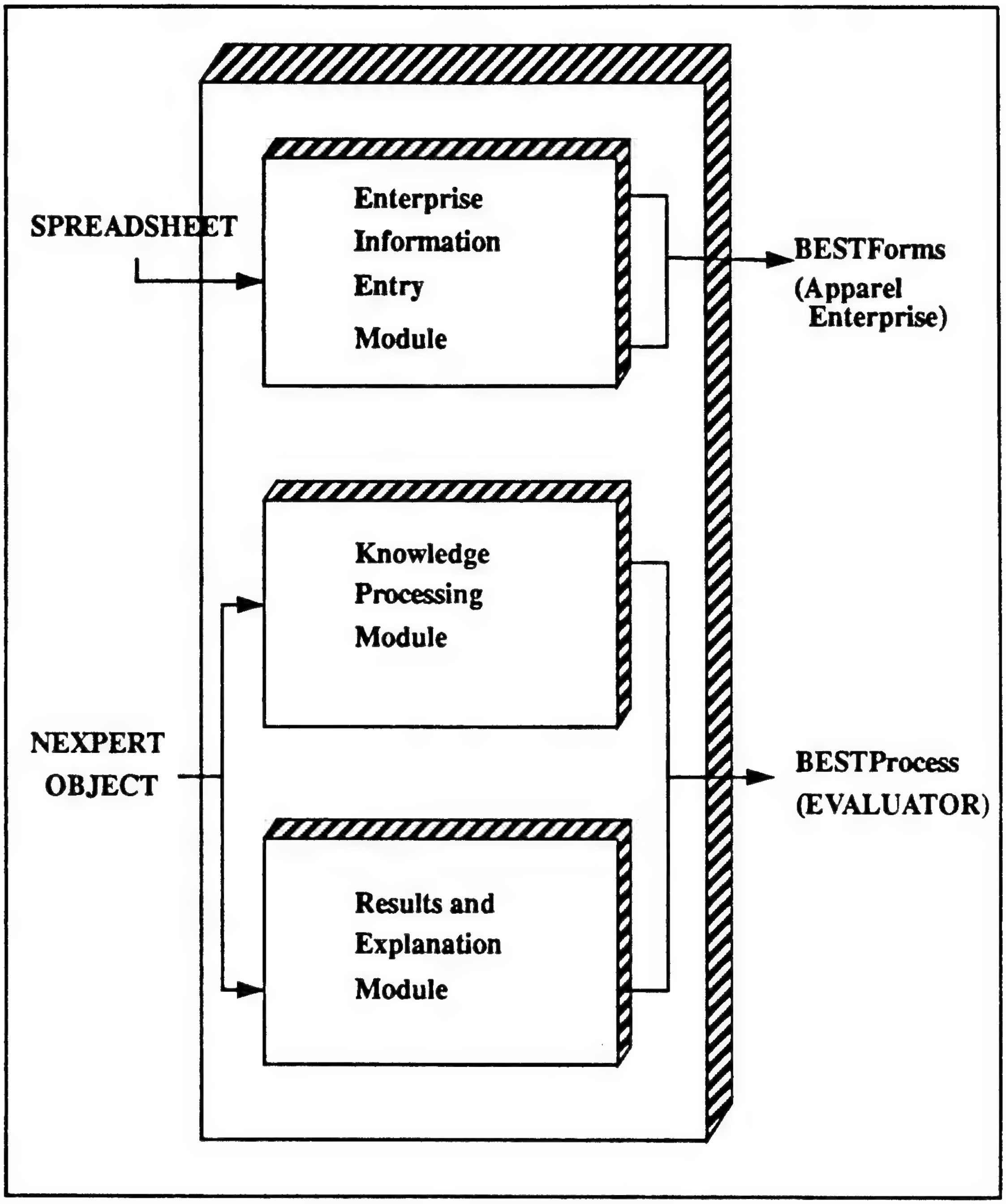

Figure 5-11. Structure of BEST

5.10.1 User Interface Requirements of BEST

The BEST system will be used by officers to evaluate enterprises based on the information provided by the participating bidders through the Enterprise Information Entry Module. This poses three major design constraints:

1. The data gathering module must be distinctly separable from the evaluating BEST system, though not always separated.
2. The interface should ensure that the data fed to the Knowledge Processing module of the BEST system is in the format required by BEST.
3. To accommodate a wide variety of users, the Enterprise Information Entry Module should be interactive, error corrective, forgiving and friendly.

There are a few additional requirements. For example, not all apparel companies may have computers to enter the data in an electronic format and some companies having computers may prefer to furnish the data on paper rather than on a diskette. In selecting the user interface, the following three interaction styles were considered:

1. Natural language interfaces
2. Menu-based systems
3. Form-filling dialogues

Based on a comparative assessment of these styles, a form-filling user interface has been selected, since it best meets the design constraints proposed for BEST (Narayanan 1991). In a form-filling interface, various questions and possible values for the corresponding answers are specified and integrated in a single screen or a logical sequence of screens, that can be scrolled up and down. The user can just fill in the required values in their respective slots. The quality of a form-filling interface depends on three major factors (Gilb 1975, Gilb & Weinberg 1977):

1. How well the forms reflect the logic of the system for which the forms serve as the input medium;
2. The clarity of the design and visual presentation of the forms;
3. The integrity of the keyed-in data (correctness and reliability) in various fields, with respect to the program which processes the input data.

In addition, Hayes mentions that a form-filling interface should also support extensive error detection and an integrated on-line help (Hayes 1985). For BEST, a form-filling interface which satisfies most of these requirements has been designed and developed and is known as BESTForms.

5.11 BESTForms Implementation

A widely used implementation vehicle was needed for the development of BESTForms. The implementation vehicle should be a simple tool which can generate the form-based user interface and have provisions to transform the data fed into the forms into a format recognized by the BEST evaluation system. Two options were available to create

BESTForms. They were

1. Nexpert Forms - a form-based user interface building tool available with Nexpert Object; and
2. A spreadsheet interface, which can either be linked directly to Nexpert Object or which can generate ASCII data from the filled forms.

Nexpert Forms

Nexpert Forms can be directly linked to Nexpert Object, by a set of command files known as Run Time Definition (RTD) files. These RTD files connect the data input locations in the forms to the corresponding data in Nexpert Knowledge Processing.

One of the major requirements of a good user interface is that user actions should be reversible. In Nexpert Forms, once one form has been completed and the next form is shown, it is not possible to go back to the previous form to make any corrections. Therefore, a mistake made by the user in one form needs to be corrected while still on that form, and before proceeding to fill the next form. Otherwise, the user is forced to restart the session. This type of interaction would be in violation of the principle of reversibility of user actions (Baecker & Buxton 1987). Therefore, Nexpert Forms did not prove to be the ideal user interface development tool for the Enterprise Information Entry Module.

Spreadsheet Templates

In a spreadsheet, all the elements of Nexpert Forms can be easily created. Moreover, errors can be corrected easily without any excessive user interaction. Hence the spreadsheet user interface was deemed to be an appropriate one for the system. Quattro has been chosen as the spreadsheet package, because Quattro can accept templates from other common spreadsheet packages such as Lotus 1-2-3 and Microsoft Excel. These templates together with their built-in programs constitute BESTForms, the front-end user interface to BESTProcess.

5.11.1 Features of BESTForms

The BEST system requires more than 500 information entities. Hence a logical separation of the input forms into groups of forms becomes necessary. A grouping based on the BEST class hierarchies would be conceptually clean and easy from the evaluator's point of view, but it would not offer any benefit to the people using BESTForms, i.e., the company personnel providing the enterprise information. Hence the grouping should be aimed at simplifying the data gathering process. The grouping of all data items pertaining to a specific department in a stand-alone form for that department would be ideal from the enterprise's point of view. Each department in the apparel manufacturing facility can then

enter data in the corresponding departmental form. For these reasons, five different forms have been designed:

- Overall Bidder Information Form
- Spreading and Cutting Room Form
- Sewing Room Form
- Quality Control Form
- Maintenance Form.

These five forms are known as the *departmental forms*. There is also a sixth form known as *Master Information Form* which consolidates the data entered in the five departmental forms. This *Master Information Form* is intended for use by the evaluator. In this form the evaluator can enter the past quality performance Score for the enterprise being evaluated. All the departmental forms have built-in programs known as *spreadsheet macros*, which check the data and convert it into ASCII data files in the format required by the BESTProcess system. All these departmental forms are also available on paper for bidders not using the electronic version (see Figure 5-12 for a part of the spreading and cutting room form).

5.11.2 Data Validation in BESTForms

The macros check the validity of the data entered in the forms. Error handling depends on the type of the erroneous datum. Three types of data are sought in the forms. They are

(i) essential data without default values,
(ii) essential data with default values, and
(iii) optional data.

If an essential datum without default value is missing or a wrong type is entered, the system cannot function any further and the user is prompted to enter a value. When the user enters erroneous or no value, the system assigns the default value to that slot but the user is still given the option to alter it. These default values would result in the worst score for the factor to which the specific data items contribute. Hence it is better for the bidder to enter the datum rather than rely on the system to assign its default value. For the optional data, the user can respond as "unknown", but here too it may lead to the worst score for the corresponding higher level factor.

If any datum is entered incorrectly, BESTForms displays an error message and pinpoints the error to the user by moving the cursor to the spreadsheet cell where the error occurred. The user is given the option either to correct only that specific datum at the error prompt itself and continue checking, or go back to the spreadsheet cell for additional

SPREADING AND CUTTING ROOM FORM

Floor and Machine Dimensions

Spreading & Cutting Floor Space (sq ft): ________
Average Length of Spreading Tables (ft): ________
Average Width of Spreading Tables (ft): ________
Average Length of Cutting Tables (ft): ________
Average Width of Cutting Tables (ft): ________

Number of Machines

Total Number of Spreading Tables: ________
Total Number of Cutting Tables/Machines: ________

Do the Spreading Machines have these features?

(Y/N or T/F)

Automatic Tensioning ________
Turn Table ________
Ply Counter ________
End Catcher ________
Surface Leveling ________
Cloth Inspection Light ________
Bolt Drive ________
Stop Control ________
Defect Sensor ________
Ply Cutter ________
Auto Ply Alignment ________

Figure 5-12. Example Departmental Form

corrections or data entry. Another important feature of the interface is that while checking, the system can interpret any uniquely identifiable set of characters and replace the set of one or more characters by the complete required data value. For example, for any question requiring a boolean answer, the response "y" or "t" is interpreted as TRUE and "n" or "f" is interpreted as FALSE and "?" is interpreted as NOTKNOWN. Another example relates to the question about type of lint cleaning system, where "b" is interpreted as "Blower Only", "s" is interpreted as "Suction" and "bs" is interpreted as "Blower and Suction" type. This uniquely identifiable set of minimum number characters makes it very easy for the user to enter data, because most of the data entry could be carried out in a single keystroke.

5.11.3 Navigation Facilities in BESTForms

Every screen in BESTForms contains navigation instructions listed at the corners or bottom of the screen. An example screen with navigation instructions is shown in Figure 5-16. The user can follow these instructions to enter data in the entire template and finally check the data and create the data file. This data file, which can be used by the BEST system for processing, is created only when all the entered data are in the correct format. The interface screens are color-coded to enable the user to easily identify the data entry locations. Also, the template is protected in such a way that data can be entered only in the data entry cells. The system displays an error message when a modification or data entry is attempted in any of the protected cells. The macros and other data cells which do not typically concern the user are hidden and are invoked only when the user checks or prints the data file. An *on-line help* facility is available in all the forms, and this can be invoked at any time during data entry. All these actions are carried out with the help of the macros built into each of the spreadsheet templates.

5.12 BEST Results

The result of BESTProcess is a set of scores on a 0 to 4 scale for all the objects identified in AEEF as factors determining the capability of the enterprise. The system provides the evaluator with a brief summary of the results. Once the evaluation is complete, the system shows a result screen which contains the *Overall_Score* for the enterprise evaluated (see Figure 5-13). The result screen also shows the breakdown of the score to the next two levels of factors under *Overall_Score*, along with their respective weights. The results can be stored in a text file. As mentioned earlier, the evaluator can choose to go through the complete evaluation process in the transcript mode to create a step-by-step account of the process and store it in a text file.

The BEST system has been tested and debugged using assumed data leading to extreme scores, as well as assumed data with realistic values. Testing with actual enterprise data from major apparel manufacturers and comparing the results with human evaluators have also been carried out. BEST results match the evaluations by industry

BID EVALUATION SOFTWARE TOOL (BEST) RESULTS)

Date: Aug 23 1991

Bidder: Enterprise C **Overall Score:** 2.48

Bid Value: $195000 **Order Size:** 93600 **Trousers/Day:** 1440

Walsh-Healey Category: Manufacturer **Contract_Type:** SBSA

Distribution of Overall Score

Criteria	Weight	Score (0 to 4 Scale)
QC Capability	0.45	2.58
Production Capability	0.35	1.95
Financial Capability	0.20	3.20
Total	1.00	2.48

Distribution of QC Capability

Criteria	Weight	Score (0 to 4 Scale)
QC Practices	0.27	3.71
QC Human Resources	0.18	2.13
Maintenance	0.06	2.51
QC Info System	0.10	2.40
QC Organization	0.10	2.00
Manufacturing Features	0.27	1.96
Past Quality	0.02	3.84
Total	1.00	2.58

Figure 5-13. Sample BEST Results

experts thus validating the system's knowledge and inference process. BEST takes approximately 3 minutes to evaluate a bid. This is in contrast to the several weeks spent when a bid is manually evaluated.

5.13 Conclusions

Most of the current vendor evaluation programs in the industry are based on past performance criteria rather than on the current manufacturing capability of the vendors. There is an absence of knowledge-based vendor rating decision support in the apparel industry. A set of factors which affects the manufacturing capabilities of an enterprise has been identified through the knowledge acquisition process. The effects of these factors on the overall possibility of getting a quality product at the right time from an enterprise has also been estimated. All the major enterprise capability factors have been abstracted and grouped into quality, production and financial capabilities.

The knowledge-based framework (Apparel Enterprise Evaluation Framework - AEEF) for evaluating utility trouser manufacturing enterprises has been developed. AEEF has been implemented as a decision support system (Bid Evaluation Software Tool - BEST), which can be used to evaluate competing apparel manufacturing enterprises to perform on a contract. BEST is implemented with the hybrid object-oriented and rule-based expert system shell Nexpert Object. The knowledge in AEEF has been structured hierarchically and represented using classes and objects and the inference mechanism is implemented as a complex set of rules in Nexpert Object. There are three separate modules in BEST namely, Enterprise Information Entry Module, Knowledge Processing Module and Results and Explanation Module. These modules can function independent of one another, but can also be plugged in together to construct an integrated decision support system. A form-based user interface (BESTForms) has also been created to obtain the information from apparel manufacturing enterprises. BEST has been tested and validated with data from apparel plants.

BEST represents the first application of knowledge-based systems technology for evaluating the capabilities of an apparel manufacturing enterprise to perform on a contract and fills a long-felt void for such a tool in the apparel industry. Though the knowledge incorporated in BEST is specific to the domain of utility trouser manufacturing, its methodology can be extended to other domains (food, medicine, automobile parts, etc.) also. While BEST is specifically suited to DoD procurement policies, its underlying framework has been developed in a modular fashion so that it can be extended to suit other organizations including commercial apparel manufacturers. Hence the apparel industry, as a whole, can stand to benefit from this framework.

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BEST: A Knowledge-Based Decision Support System for Source Selection

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LATEST INFORMATION ON BEST

Abstract

The practice of subcontracting or *outsourcing* some or all the operations involved in manufacturing products is prevalent in many industries, especially in the apparel industry. The buying organization typically receives bids from several companies that offer to carry out these operations. The process of determining whether a manufacturing enterprise is capable of producing the required quantity of the commodity at the right time and of the specified quality is fairly complex and involved. A knowledge-based approach has been adopted to identify the major factors that affect the capability of an apparel manufacturing enterprise and to determine the effect of these factors on the overall possibility of obtaining a quality product at the right time.

This knowledge-based framework has been implemented as a decision support system known as Bid Evaluation Software Tool (BEST). BEST can be used by apparel companies to select contractors based on a set of evaluation criteria. A form-based Graphical User Interface, known as BESTForms, has also been built to obtain the data from an apparel enterprise. BEST has been successfully tested and validated with the assistance of Levi Strauss and Company. The highlights of BEST are presented in this paper.

1. INTRODUCTION

The Department of Defense is the single largest consumer of apparel items in the free world procuring approximately $1 billion worth of apparel every year. The buying organization, Defense Personnel Support Center (DPSC), typically receives bids from several companies that offer to supply the desired product. The process of determining whether a manufacturing enterprise is capable of producing the required *quantity* of the commodity at the right *time* and of the specified *quality* is fairly complex and involved.

The old practice of using sealed bid procedures and awarding contracts to the lowest bidder is giving way to Best Value Procurement. Such an informed and knowledge-based procurement approach would not only help the government but would also have an overall beneficial effect on the apparel industry.

Outsourcing is an accepted practice in the US apparel industry and companies are beginning to develop evaluation systems for selecting potential contractors. BEST has been designed to

[1]To Whom Correspondence Should be Addressed.

fill the need for such an objective contractor evaluation system.

2. THE APPAREL ENTERPRISE EVALUATION FRAMEWORK

The factors contributing towards the overall capability of an enterprise to produce quality output in a short throughput time have been identified through an expert knowledge acquisition process consisting of an industry questionnaire, interactions with apparel contracting experts in industry and DPSC, and literature. The details can be found in Narayanan and Jayaraman[2].

Figure 1 shows the groups of factors considered in the evaluation of an enterprise and these range from the assessment of production capability to maintenance practices. The principal criteria for evaluating the performance of an enterprise on a contract are shown in Figure 2. Industry experts ranked "meeting quality requirements" as the most important factor in their evaluation process and sewing was considered to be the most important process in their evaluation of process capabilities. The obtained knowledge has been analyzed, classified and weighted using a hierarchical decomposition process (Figure 3). The decision support system based on this knowledge framework utilizes observable data from the enterprise's manufacturing facility and transforms the data into quantified *production*, *quality* and *financial* capability indices and an *overall score* (Figures 4 and 5). This framework is known as the Apparel Enterprise Evaluation Framework (AEEF).

3. STRUCTURE OF BEST

AEEF has been implemented in Level-5 Object, a knowledge-based system (KBS) shell that runs under the MS-Windows environment. BEST consists of two principal modules -- BESTForms and BESTProcess. BESTForms is used to obtain the necessary information for evaluating a bidder, while BESTProcess is the reasoning module that utilizes the data in BESTForms to arrive at an overall score for the bidder.

BESTForms: BESTForms can be customized by the evaluating officer to suit the garment being procured. This customization can be accomplished through a graphical user interface (GUI) designed with on-line help. As shown in Figure 6, each form seeks information on one aspect of an apparel enterprise. For example, in Figure 7, information about the Sewing Room is sought from the bidder. Figure 8 shows a screen from the Spreading & Cutting Room Form. Along with the bid solicitation, disks containing BESTForms can be mailed by the evaluating officer. The bidders can easily enter the information on the disk (or on a hard copy) and send it back with their bids.

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The evaluating officer can also assign suitable weights for the various evaluation parameters pertaining to the procurement. Likewise, the parameters associated with the contract can be assigned by the officer. In short, BESTForms provides a great deal of flexibility to the officer in tailoring BEST to suit a specific procurement. BESTForms is also available in hard-copy form.

BESTProcess: BESTProcess, the problem-solving engine in BEST, utilizes the data in BESTForms, the weights and parameters assigned by the evaluating officer and comes up with an overall score (on a 0-4 scale) for the bidder (Figures 9 and 10).

4. FIELD TESTING AND VALIDATION

BEST has been tested and validated with the participation of Levi Strauss & Company. Using BESTForms, the contracting expert at Levi's gathered data from apparel plants which were subsequently processed through BEST. The ranking of the firms by BEST was identical to that of the human expert thus validating the reasoning process in BEST. The expert was able to easily alter the weights and parameters using the GUI to suit the specific procurement and confirmed the system's ease of use. The contracting expert also reviewed and validated all the weights and parameters in BEST. Thus, the field testing of BEST has been successful and it has been validated in the field.

5. ROLE AND IMPORTANCE OF BEST IN APPAREL PROCUREMENT

BEST has been developed to provide a knowledge-based decision support system for contracting officers at apparel companies engaged in outsourcing and DPSC to assist them in their evaluation tasks. Using BEST, officers can apply the evaluation criteria uniformly, and objectively, across all potential contractors. Moreover, for the bidders, the bid preparation process will be greatly simplified (and automated) since the information is sought in a logical and consistent format (in BESTForms) from all bidders.

BEST also has a potential role in facilitating *electronic commerce* (EC) in the apparel industry. BESTForms represents a modest step in paving the way for electronic data interchange (EDI) between an apparel manufacturer and its contractors, or between the DoD and its apparel suppliers. Bidders can conceivably submit the necessary information on disks that can be loaded at the selecting manufacturer's facility (or DPSC) and used with BEST. Such an approach will reduce the large amounts of existing paperwork and will contribute to fewer errors in data transfer. Data integrity can be easily ensured prior to the award of a contract. Additionally, once a bidder's information is present in a database at the selecting apparel manufacturer (or DPSC), the bidder will only be required to update the information (on subsequent bids) and there will be no need to resubmit all the data. Moreover, in the event of a mobilization (e.g., Desert Shield/Storm), or Quick Response needs, DPSC (or the apparel manufacturer) would have a database of contractors' capabilities that could be quickly tapped. In the long-term, apparel manufacturers (and DPSC) can utilize the proposed national *information superhighway* to set up a network (or dial-in) facility and bidders can enter the

information directly in the apparel company's (and DPSC's) computers thus speeding up the response process on a solicitation. Thus, BEST can play a critical role in facilitating EDI leading to EC in the apparel industry.

BEST Index and Civilian Apparel Manufacturers: Since a large number of apparel companies (in the civilian market) are actively engaged in subcontracting, BEST can assist them in evaluating potential contractors. In the long term, an index similar to the Department of Transportation's ranking of airline performance (based on on-time arrival, baggage handling and customer complaints) can be developed for the apparel industry. Such an index can be maintained by an independent agency (similar to the Underwriter Laboratories for appliances). And apparel companies can use the BEST Index as a reliable indicator of contractor performance to select contractors.

Acknowledgments

The authors would like to acknowledge the major contributions made by Mr. Sambasivan Narayanan on the development of the Nexpert Object version of BEST. Dr. Howard Olson also contributed during the initial phases of the effort and deserves appreciation. Finally, the authors thank the U.S. Defense Logistics Agency for funding this research effort and Mr. Michael Marazzo of Levi Strauss & Company for his participation in testing and validating BEST. The American Apparel Manufacturers Association assisted with the mailing of questionnaires and the participation of its member companies in the effort is thankfully acknowledged.

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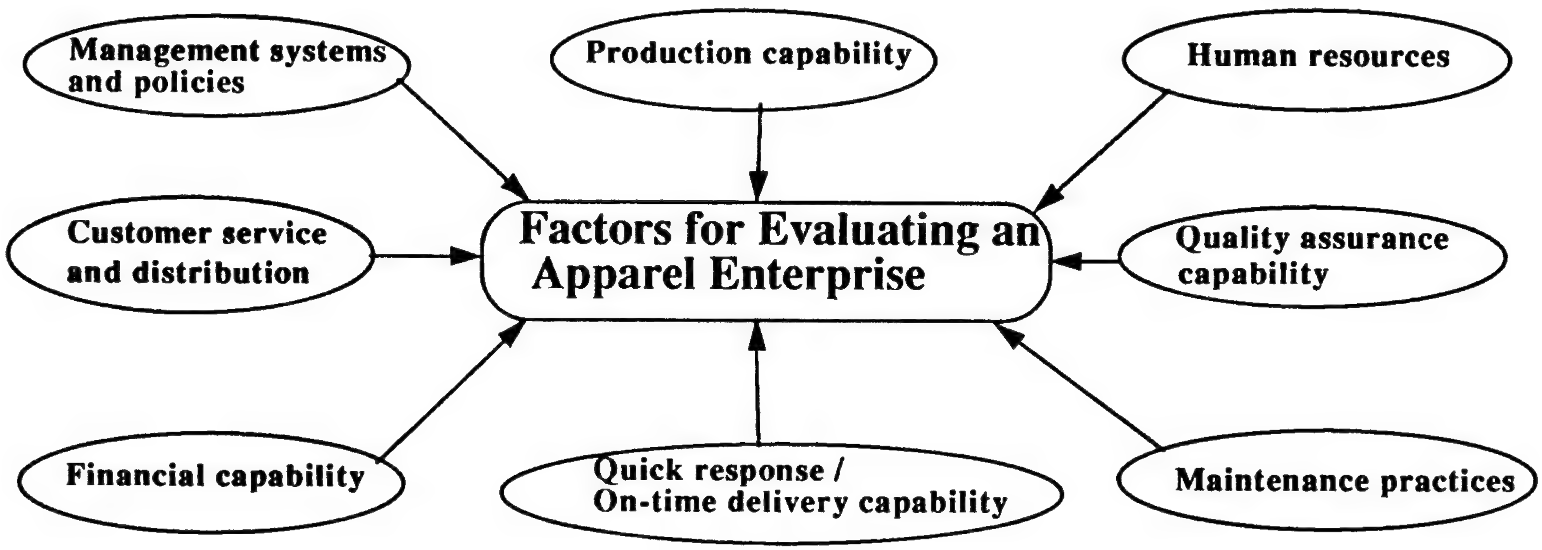

Figure [illegible]1. Groups of Factors for Evaluating an Apparel Enterprise

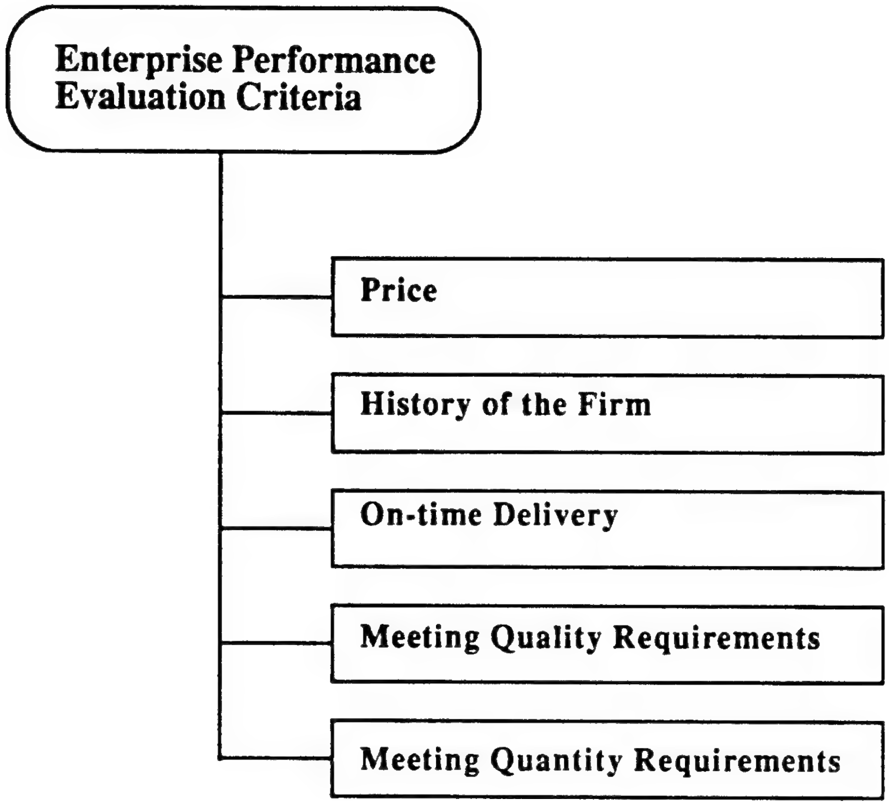

Figure 2. Criteria for Evaluating the Performance of an Enterprise

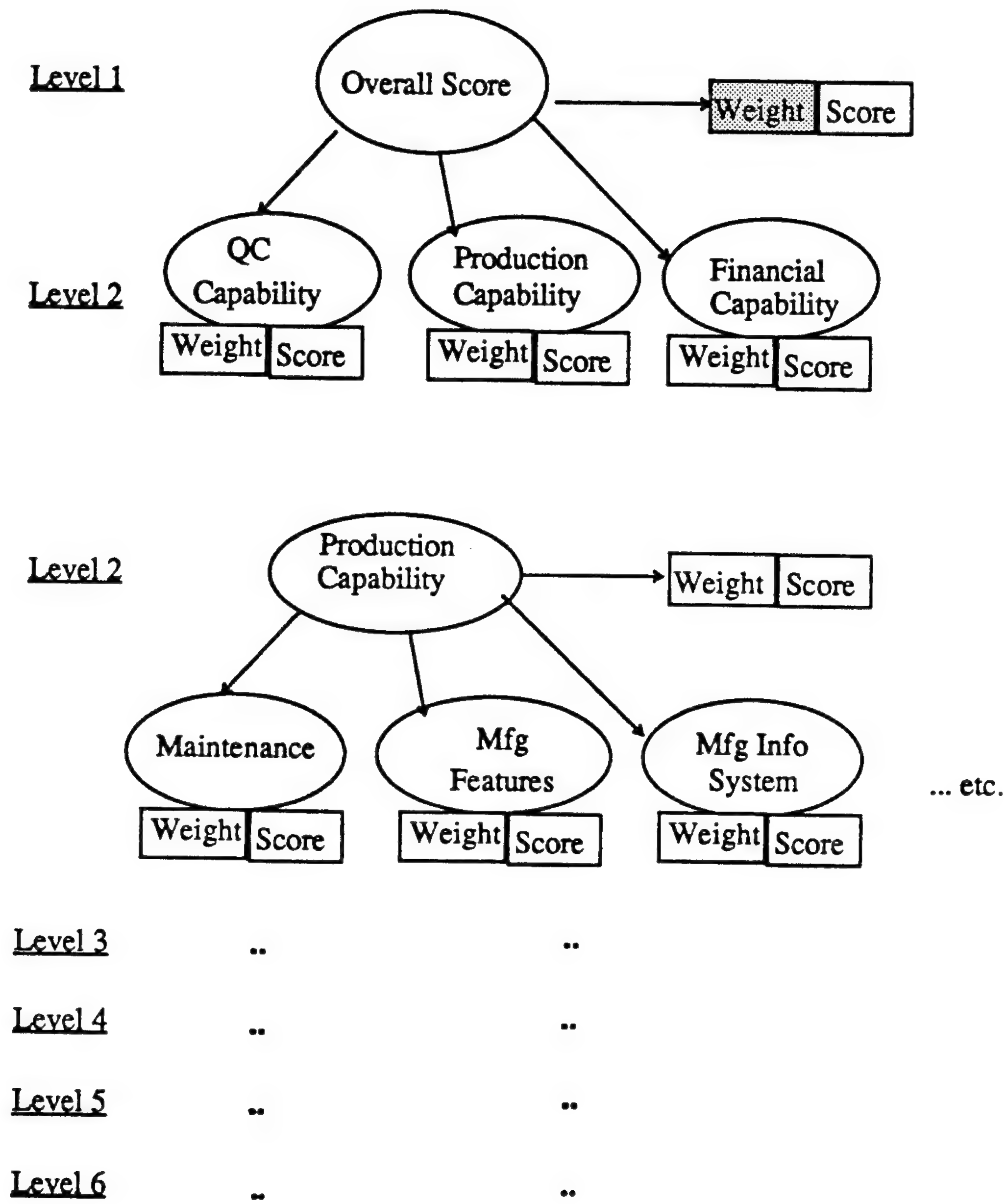

Figure 3. Inheritance of Properties by Lower Level Classes

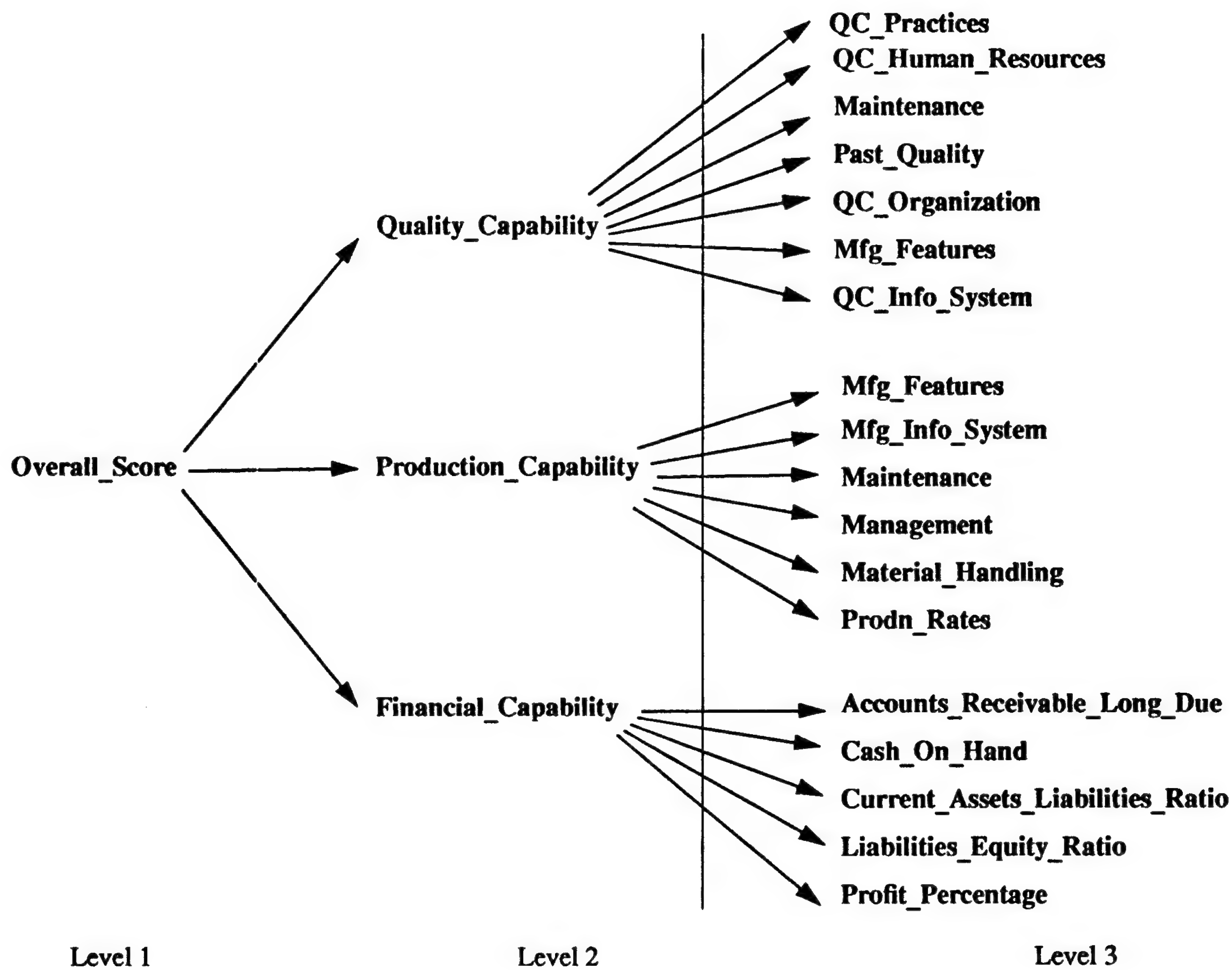

Figure 4. Decomposition of the Class *Overall_Score*

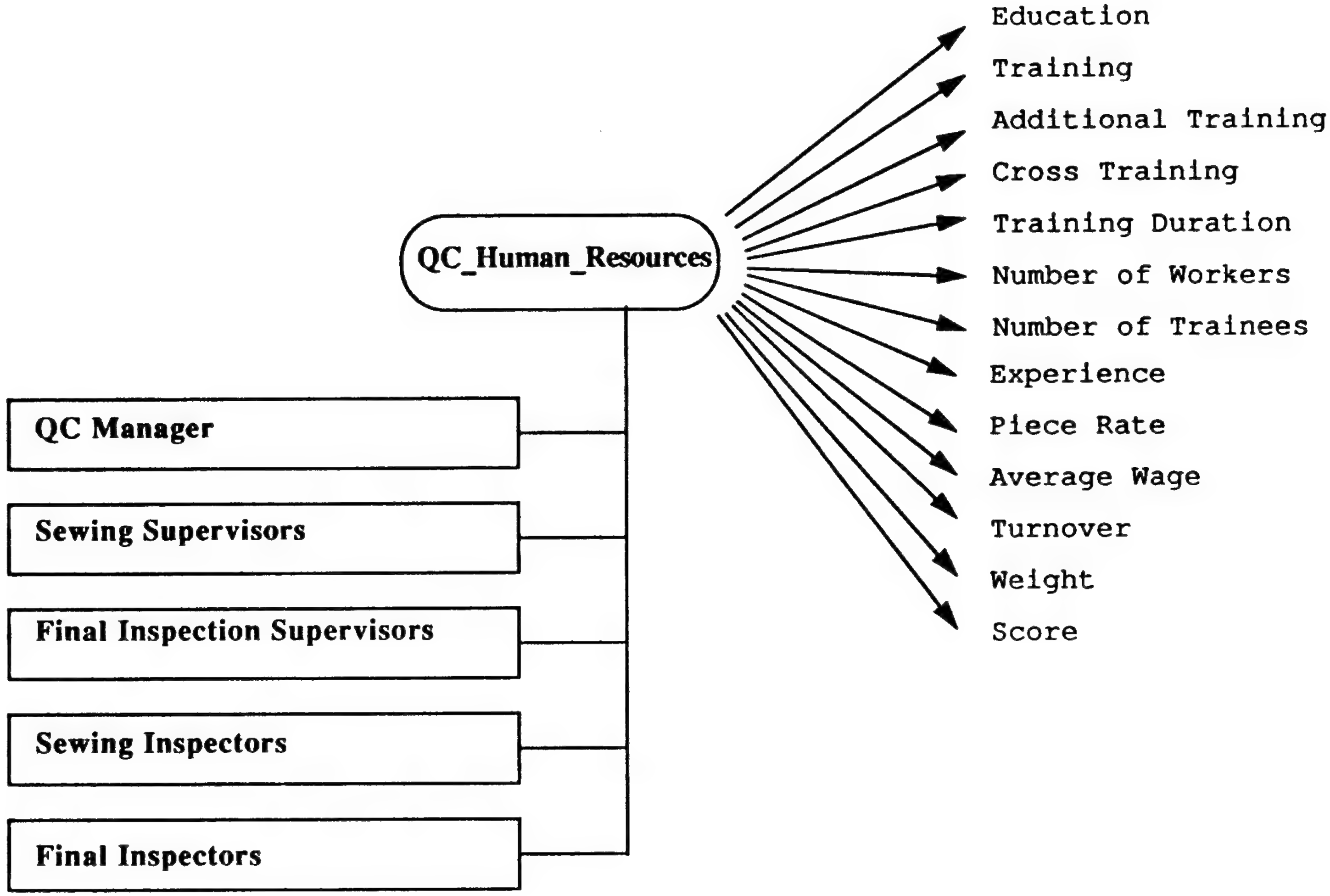

Figure 5 . Categories and Attributes of Personnel in the QC Department

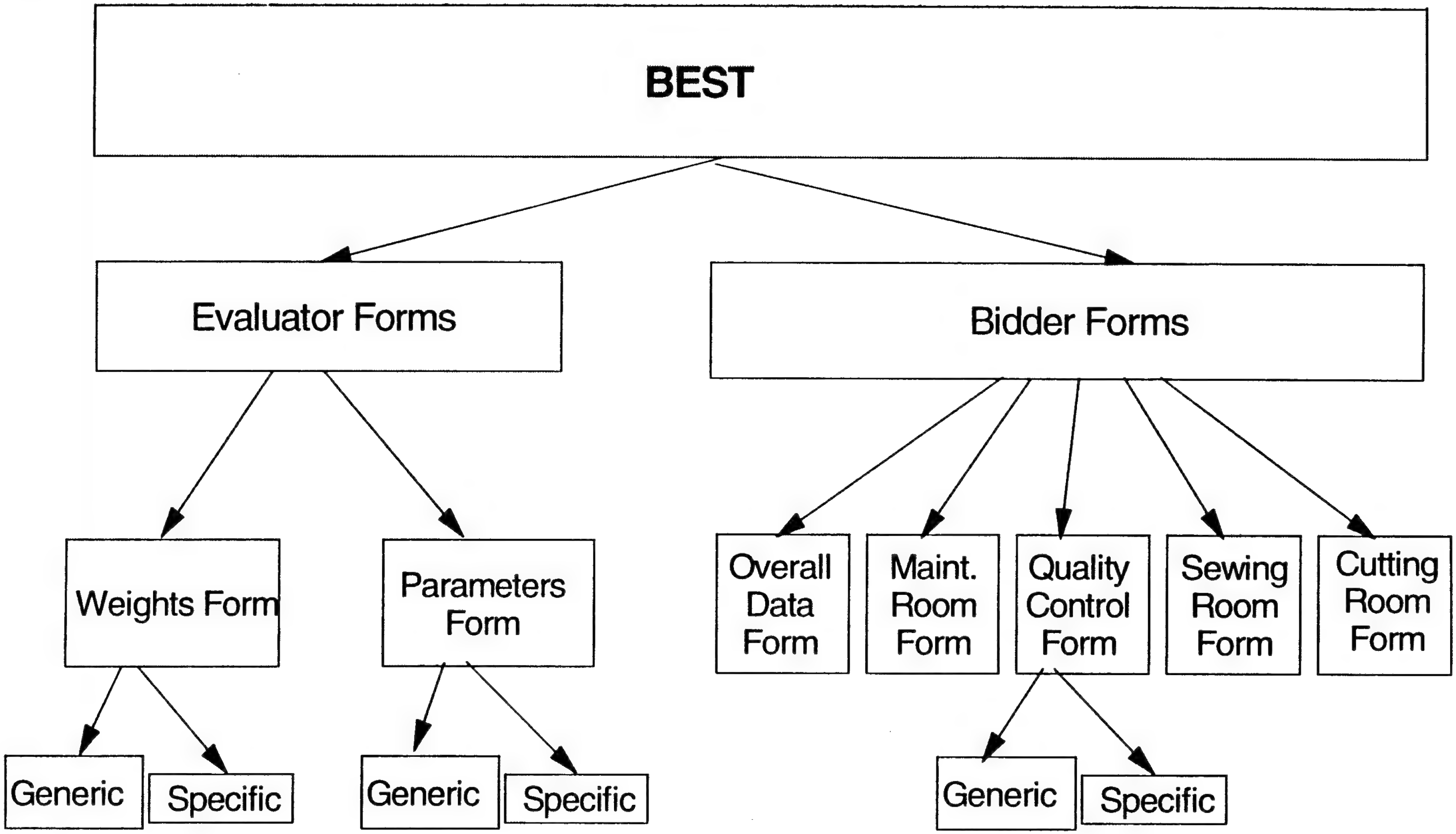

Figure 6 The BEST System

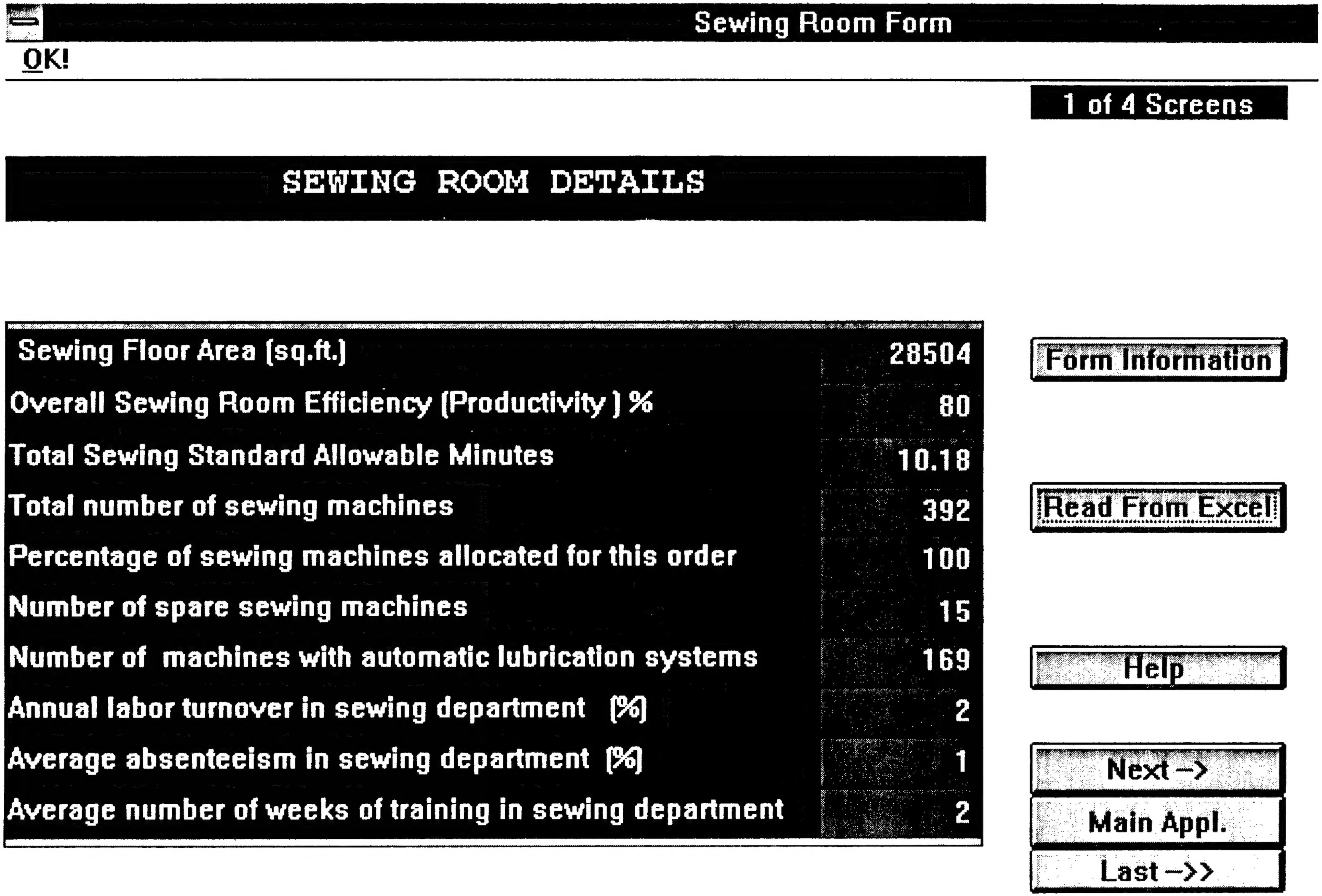

Figure 7. A Screen From the Sewing Room Form

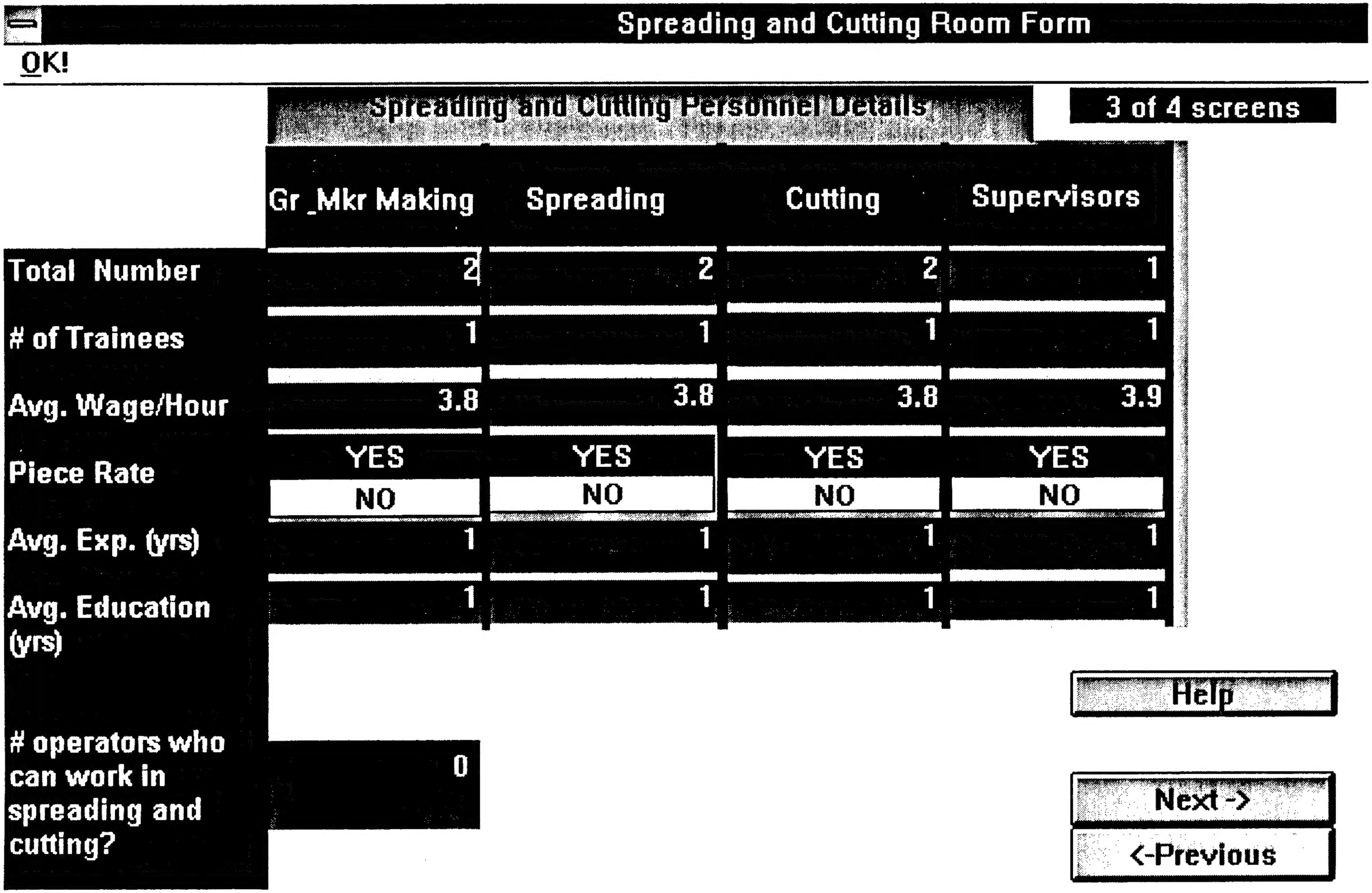

Figure 8. A Screen From the Spreading & Cutting Form

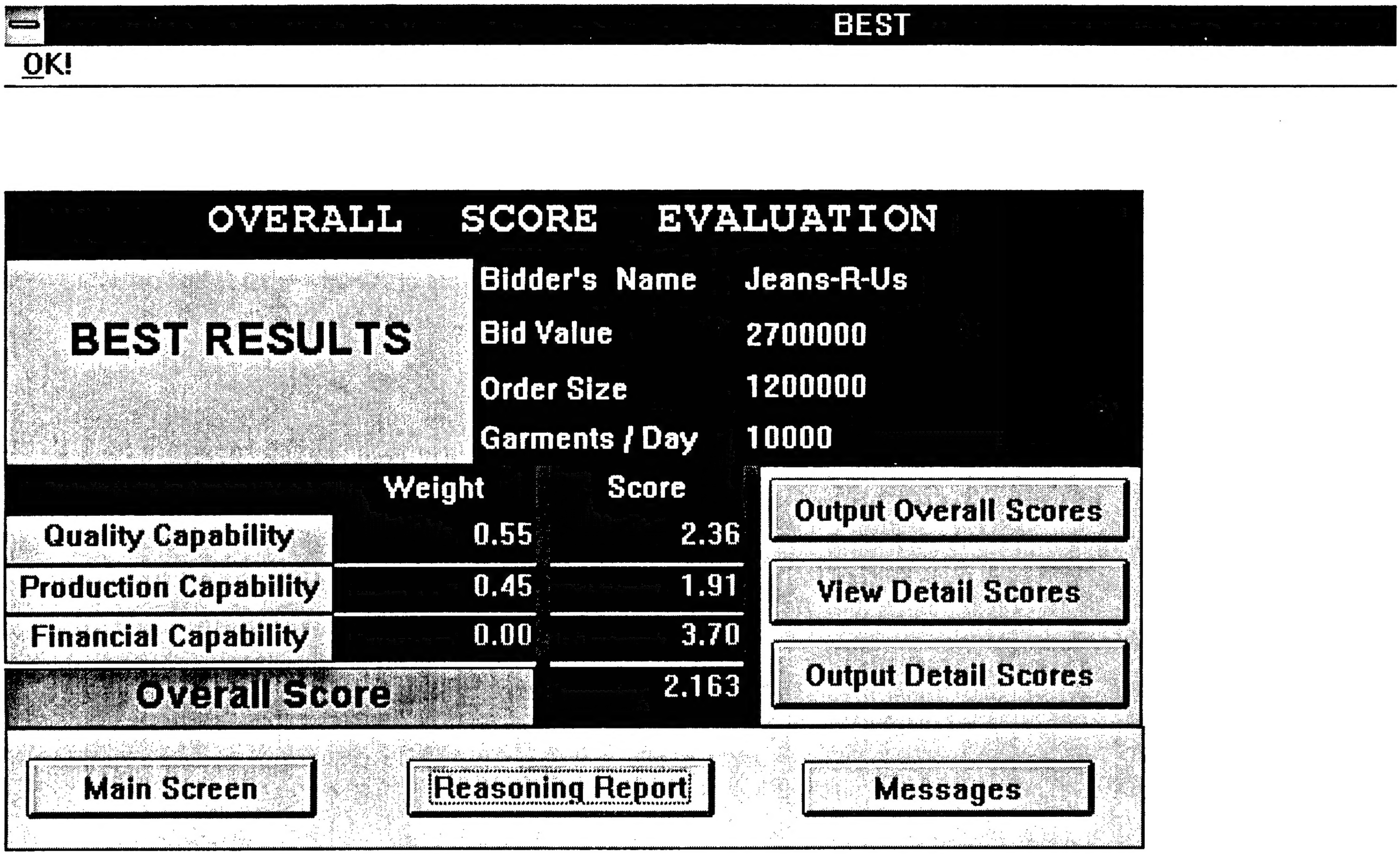

Figure 9 BEST Results

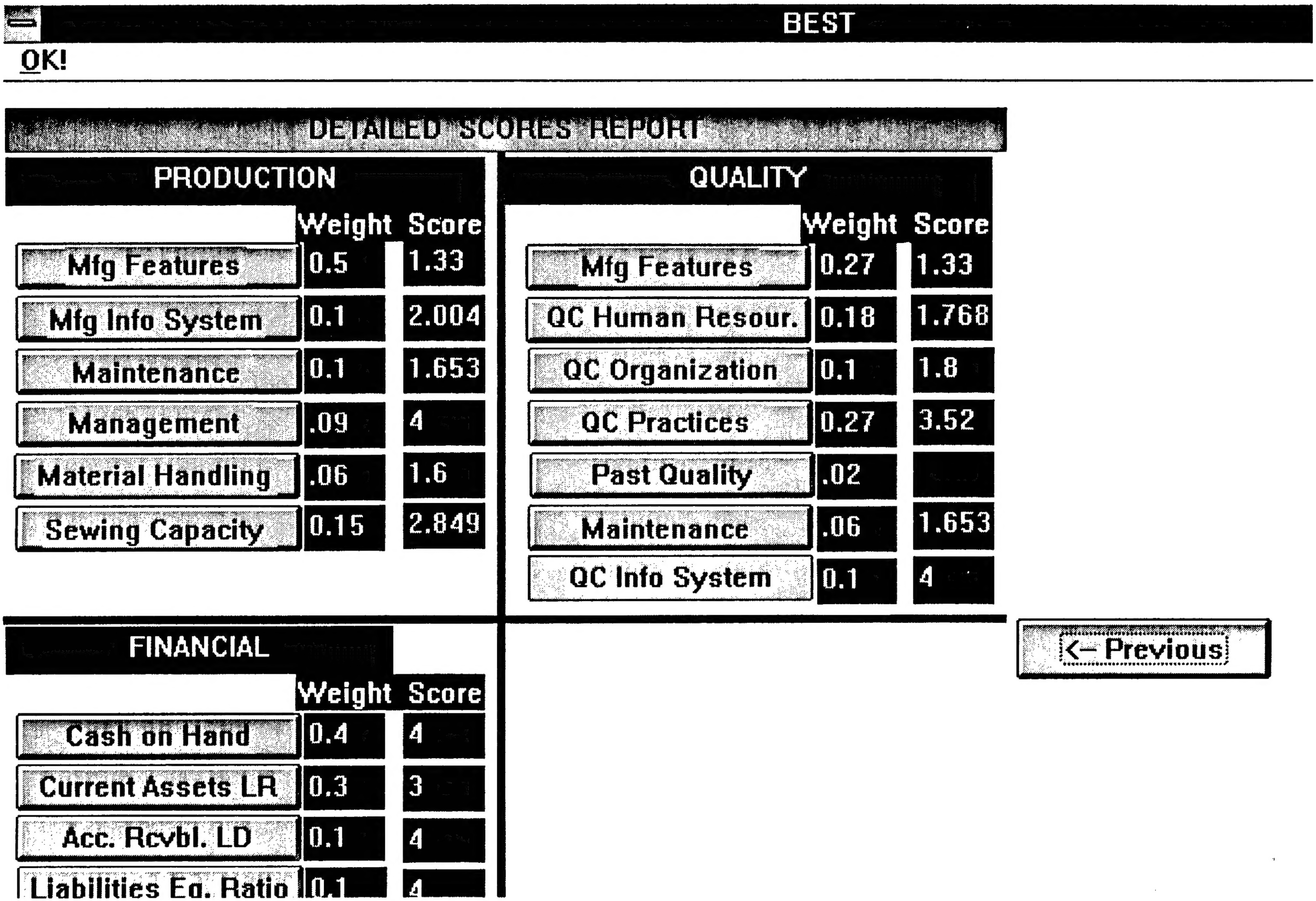

Figure 10. Detailed Distribution of BEST Results